

# **Verification and Improvement of the DSM2 Extension Model for the South Bay Aqueduct, California Aqueduct, and Delta Mendota Canal**

A Report to the Municipal Water Quality Investigation Program



Bay Delta Office  
Operation and Maintenance  
Municipal Water Quality Investigations  
DEPARTMENT OF WATER RESOURCES

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# **Verification and Improvement of the DSM2 Extension Model for the South Bay Aqueduct, California Aqueduct, and Delta Mendota Canal**

## **Chapter 1: Introduction**

An important part of the Department of Water Resources' (DWR) Municipal Water Quality Investigation (MWQI) program is to develop short- and long-term forecasting simulation capabilities for the California Aqueduct. Similar capabilities for the Delta have been developed in order to provide forecasted quality of inflows at Banks and Jones Pumping Plants for the California Aqueduct and Delta Mendota Canal (DMC). The short- and long-term forecast for both the Delta and California Aqueduct relies on hydrologic and water quality modeling using DWR's Delta Simulation Model II (DSM2). The original DSM2 extension model for the California Aqueduct, South bay Aqueduct and Delta Mendota Canal (briefly DSM2 Aqueduct Model) was developed by CH2MHILL in 2005. Since then a lot of work has been done by BDO, O&M, and MWQI to verify and improve the DSM2 Aqueduct model. The report will document our work on the DSM2 Aqueduct model which includes: (1) extended the model simulation period from 3 years starting January 1, 2001 to 21 years starting from January 1, 1990; (2) modified the ways to treat gains / losses of water as results of seepage, evaporation, rainfall, storm water inflow, meter reading errors and etc.; (3) enhanced the model's capability of calculating water quality by adding two more constituents, dissolved organic carbon (DOC) and Bromide; and (4) incorporated inflows from ground water and storm water.

### **1.1 Brief Description of California Aqueduct, South Bay Aqueduct, and DMC**

The California Aqueduct is the primary conveyance facility for the SWP (Figure 1-1). The section of the California Aqueduct modeled with DSM2 extends over 400 miles from Banks Pumping Plant to Silverwood Lake. Along that stretch there are many canals, several siphons and tunnels, 66 check structures, and two reservoirs, O'Neill Forebay (in-line) and San Luis Reservoir. Both the South Bay Aqueduct and the West Branch of the California Aqueduct are included in the model. The South Bay Aqueduct, which begins at the South Bay Pumping Plant, contains 7 checks, and ends at the Santa Clara Tank, is comprised of open channels, siphons, and tunnels. The West Branch simulated in the model starts from the bifurcation to Oso Pumping Plant, and ends at the Pyramid Lake. It is composed mostly of open channels and an in-line reservoir, Quail Lake. The Aqueduct is managed by four field divisions:

- Delta Field Division, which includes Banks Pumping Plant to O'Neill Forebay and the South Bay Aqueduct
- San Luis Field Division, which includes San Luis Reservoir, O'Neill Forebay, and the 103-mile, joint-use San Luis Canal, which extends from O'Neill Forebay to Check 21
- San Joaquin Division, which includes Check 21 to Edmonston Pumping Plant and the Coastal Aqueduct
- Southern Division, which includes the East Branch below Edmonston Pumping Plant and the West Branch to Los Angeles County

A series of pumping plants on the Aqueduct provides incremental lifts in head where required to maintain the average downstream slope of three inches per mile along the Aqueduct. These pumps include the Banks Pumping Plant, the Dos Amigos Pumping Plant, the Buena Vista Pumping Plant, the Teerink Pumping Plant, the Chrisman Pumping Plant, and the Edmonston Pumping Plant. The Oso Pumping Plant, the Warne Powerplant, and the Castaic Powerplant are located on the West Branch. The Castaic Powerplant is below Pyramid Lake and, thus, is not included in this model. On the south side of the

Tehachapi Mountains (East Branch), pumping and power generating plants include the Alamo Powerplant, the Pearblossom Pumping Plant, the Mojave Siphon Powerplant, and the Devil Canyon Powerplant. The Devil Canyon Powerplant is located below Silverwood Lake and, thus, is not included in the model. Figures 1-2 through 1-5 provide an overview of the four field divisions, including the facilities and check structures in each.

The California Aqueduct delivers water to agricultural and municipal contractors through over 270 diversion structures. The majority of diversions are made between O'Neill Forebay and Edmonston Pumping Plant. The largest contractor south of Edmonston is the Metropolitan Water District of Southern California.

The South Bay Aqueduct is part of the Delta Field Division of the California Aqueduct. It was the first delivery system completed under the SWP and is used to convey water from the Sacramento-San Joaquin Delta to the Alameda County and Santa Clara Valley Water districts. The South Bay Aqueduct consists of 42.18 miles of canals and pipelines. It begins at the South Bay Pumping Plant, drawing water from Bethany Reservoir and lifting it 566 feet. The South Bay Aqueduct ends at the Santa Clara Terminal Reservoir. The Del Valle Branch Pipeline branches off of the South Bay Aqueduct 18.57 miles downstream of the pumping plant and delivers water to Lake Del Valle. The South Bay Aqueduct has a design capacity of 300 cfs.

The Delta–Mendota Canal (DMC) is a 117 mi (188 km) aqueduct in central California. It was completed in 1951 and is operated by the United States Bureau of Reclamation (USBR) and the San Luis Delta Mendota Water Authority. DMC is part of the Central Valley Project and its purpose is to replace the water in the San Joaquin River that is diverted into Madera Canal and Friant-Kern Canal at Friant Dam. The canal begins at the C.W. Bill Jones Pumping Plant, which pumps water 197 ft (60 m) from the Sacramento-San Joaquin Delta. The canal runs south along the western edge of the San Joaquin Valley, parallel to the California Aqueduct for most of its journey, but it diverges to the east after passing San Luis Reservoir, which receives some of its water. The water is pumped from the canal and into O'Neill Forebay, and then it is pumped into San Luis Reservoir by the Gianelli Pumping-Generating Plant. Occasionally, water from O'Neill Forebay is released into the canal. The Delta–Mendota Canal ends at Mendota Pool, on the San Joaquin River near the town of Mendota, 30 mi (48 km) west of Fresno. The Delta–Mendota Canal capacity is 4,600 cu ft/s (130 m<sup>3</sup>/s) and gradually decreases to 3,211 cu ft/s (90.9 m<sup>3</sup>/s) at its terminus. The DMC delivers water to contractors through over 200 turn-outs. Four wasteways extend westward from the DMC toward the San Joaquin River. These include the Westley Wasteway, the Newman Wasteway, the San Luis (Volta) Wasteway, and the Firebaugh Wasteway. There are no pumping plants or generating plants on the DMC aside from the Tracy Pumping Plant.

[illegible]

### Figure 1-1 California Aqueduct State Water Project



Figure 1-2 Delta Division including South Bay Aqueduct plus Delta-Mendota Canal

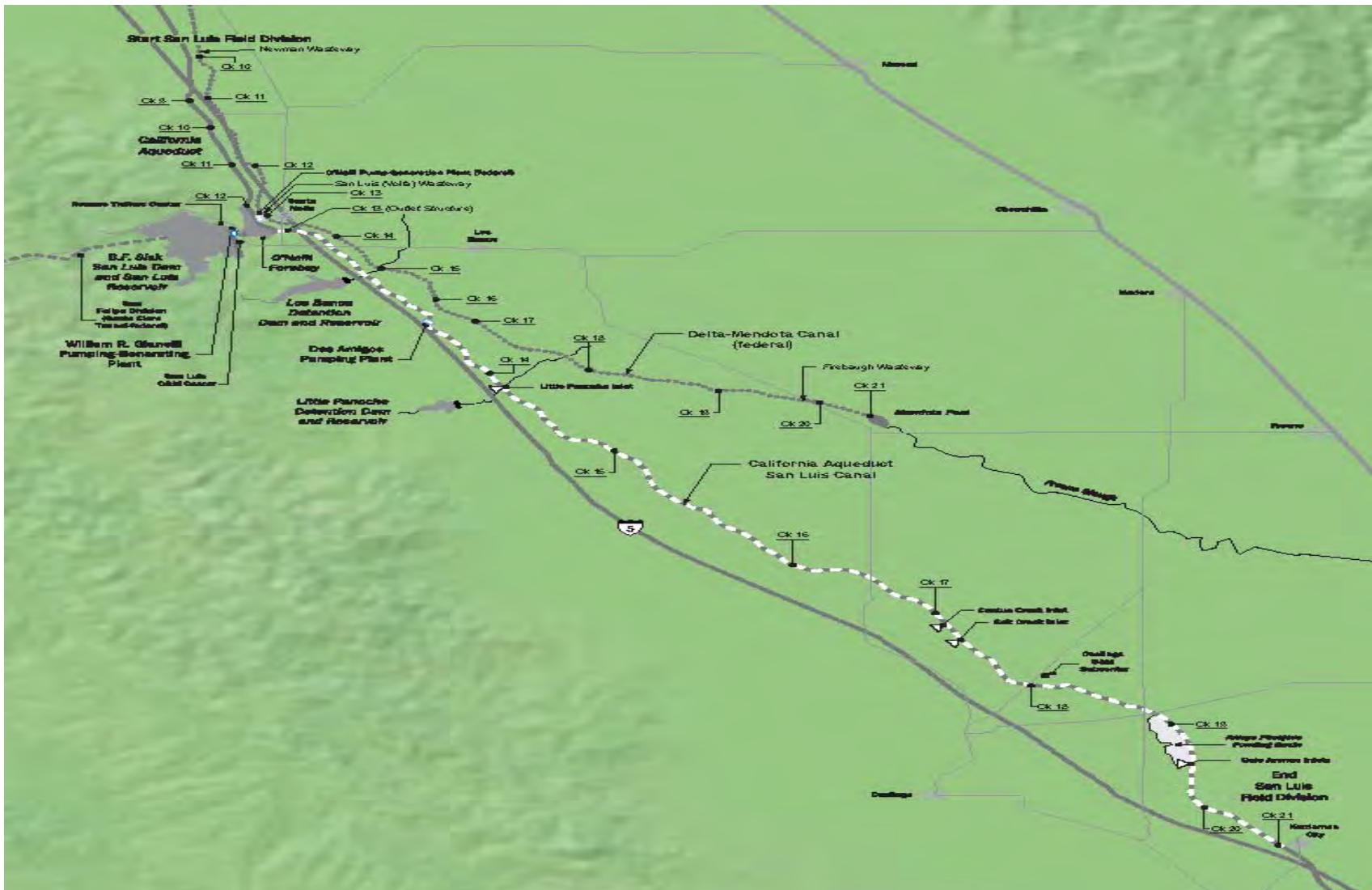


FIGURE 1-3 California Aqueduct San Luis Division plus Delta-Mendota Canal

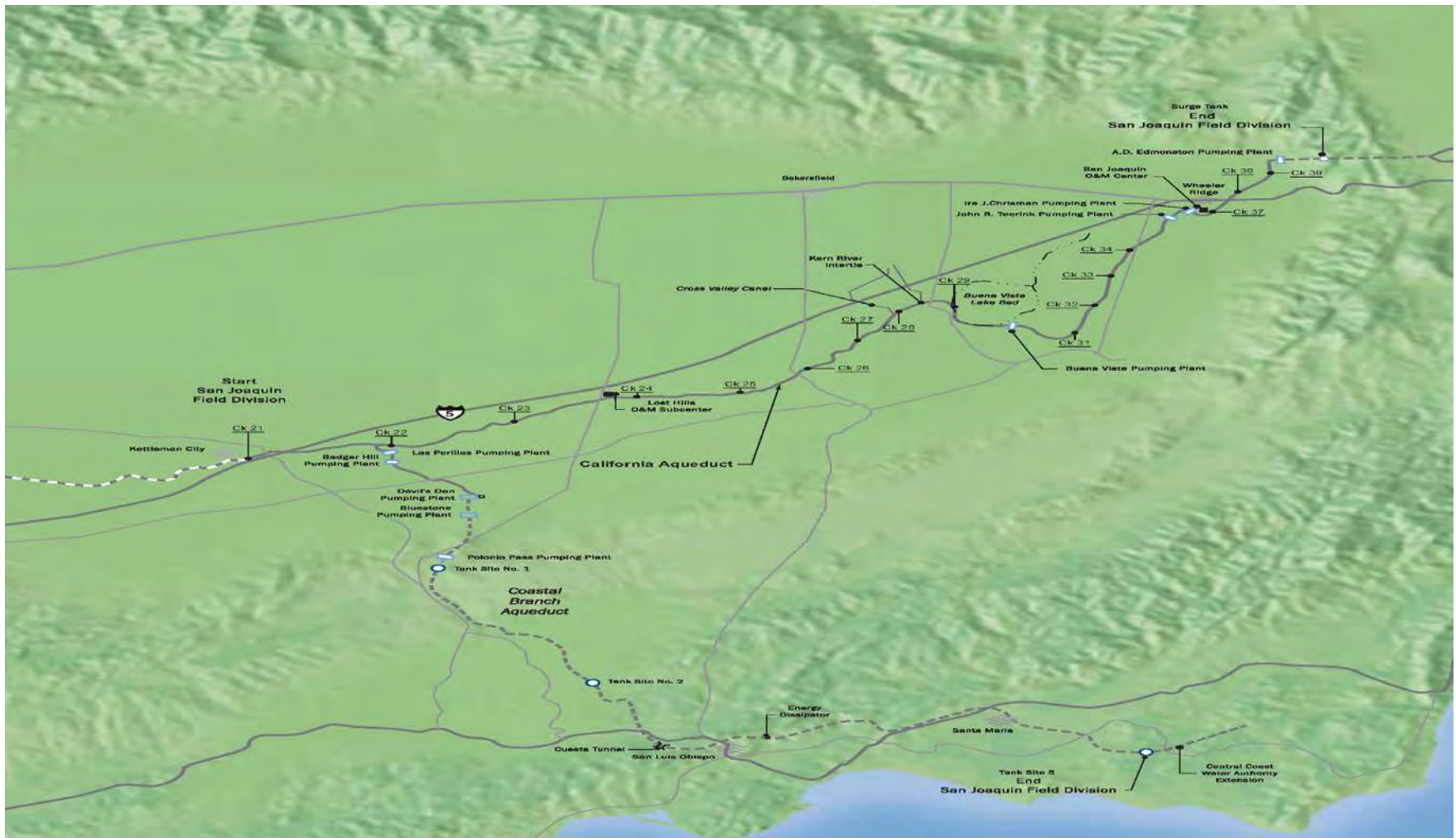


Figure 1-4 California Aqueduct San Joaquin Division



Figure 1-5 California Aqueduct Southern Division

## 1.2 Introduction to the DSM2 Aqueduct model

The DSM2 model has three separate components: HYDRO, which calculates water velocities and elevations; QUAL, which calculates EC and other constituents throughout the Delta; and PTM, which is a particle tracking model. HYDRO provides the flow input for QUAL and PTM. The DSM2 Aqueduct model only used HYDRO and QUAL. DSM2 HYDRO relies on appropriate grid resolution to run with enough accuracy and efficiency.

For the extension model, which was developed by CH2MHILL in 2005, grid nodes are located where inflows / outflows occur, or where channel geometry changes occur, usually check structures are located. Table 1-1 is a list of DSM2 nodes and DSM2 channels with their locations. With 66 check structures, a starting node at Banks Pumping Plant, and an ending node at Silverwood Lake, the main stem of the Aqueduct contains 67 channels and 68 nodes. The DMC has 21 checks between Jones Pumping Plant and the Mendota Pool, so it is modeled with 21 channels and 22 nodes. The South Bay Aqueduct begins at the South Bay Pumping Plant, contains 7 checks, and ends at the Santa Clara Tank, so it contains at least 8 channels and 9 nodes. The West Branch contains one check structure and an in-line reservoir, so it equates to at least 2 channels and 3 nodes in DSM2.

South Bay Pumping Plant data is treated as a diversion from the main stem of the Aqueduct (at Check 1) and as an inflow to the South Bay Aqueduct through an object-to-object transfer. Likewise, pumping to the West Branch from the OSO Pumping Plant data is treated as a diversion from the main stem of the Aqueduct at DSM2 node 448 through an object-to-object transfer. O'Neill Forebay is regulated downstream by Check 13, so flow is not allowed to travel freely from O'Neill to the downstream pool in DSM2. An object-to-object transfer is used to carry water from O'Neill to the upstream node of the downstream channel (node 414, channel 415). The transfer is calculated as the flow through Dos Amigos Pumping Plant plus any diversions in pool 13 (there are no inflows to pool 13). The water exchange between O'Neill Forebay and San Luis Reservoir, and between O'Neill Forebay and DMC is modeled as object-to-object transfer in the model.

The 116 mile Coastal Branch splits from the main line 11.3 mi (18.2 km) south-southeast of Kettleman City transiting Kings County, Kern County, San Luis Obispo County, and Santa Barbara County to deliver water to the coastal cities of San Luis Obispo, Santa Maria, and Santa Barbara. The Coastal Branch of the SWP was not modeled directly. Instead, the pumping to the Coastal Branch from the main stem of the Aqueduct through the Las Perillas Pumping Plant is treated as a diversion from the main stem of the Aqueduct at DSM2 Node 424.

The DSM2 Aqueduct model developed by CH2MHILL in 2005 was based on version 6 of DSM2. The model was calibrated by comparing model calculated flows, stages and EC against measured data for a period that covers three-years beginning January 1, 2001. Model validation was not conducted using a separate input set for a time period different from the calibration time period. Like any model, a lot of assumptions are assumed when the DSM2 Aqueduct model was developed. The following is a list of those assumptions / limitations.

- (1) Gains/losses: Results of water balance calculations based on inflow/ outflow data from various sources indicate gains / losses must be considered in order to maintain the measured water levels of the Aqueduct.
- (2) Reservoir operations: DSM2 treats reservoirs as completely mixed, vertical-walled bodies of water.
- (3) Gate operations : The check structures are modeled as broad-crested weirs, with the invert elevations fixed to control flows.

- (4) Diversion data interval: The data quantifying diversions from the system are aggregated on a monthly basis. These data were used to specify the diversions in the model, and were assumed to remain constant over the month.

**Table 1-1** Locations of DSM2 Nodes for California Aqueduct, South Bay Aqueduct and Delta Mendota Canal

Pool No	DSM2 Node	DSM2 Channel	Feature	Mile post	Invert Elev(ft)	Canal length(ft)
<b>California Aqueduct</b>						
1	401	401	Check 1	5.95	214	13,880
2	403	402-403	Check 2	12.01	210.5	32,030
3	404	404	Check 3	18.29	208.7	33,170
4	405	405	Check 4	23.99	207.2	30,090
5	406	406	Check 5	29.73	205.6	30,280
6	407	407	Check 6	34.24	204.4	23,800
7	408	408	Check 7	39.91	203	29,950
8	409	409	Check 8	45.97	201.4	32,000
9	410	410	Check 9 / Orestimba Creek Siphon	51.3	200	28,440
10	411	411	Check 10	56.86	198.1	29,320
11	412	412	Check 11	61.4	196.7	23,730
12	413	413	Check 12	66.71	195.3	28,015
			O'Neill Forebay	66.74	195.3	
			O'Neill Forebay Outlet	70.85	195.5	
13	414	414-415	Dos Amigos Pumping Plant Check 13	86.73	192.2	106,756
14	416	416	Check 14	95.06	306.7	43,035
15	417	417	Check 15	108.5	300.5	71,005
16	418	418	Check 16	122.07	295.2	71,670
17	419	419	Check 17	132.95	291.4	57,410
18	420	420	Check 18	143.23	293.1	54,320
19	421	421	Check 19	155.64	289.5	65,520
20	422	422	Check 20	164.69	288.4	47,730
21	423	423	Check 21	172.4	289.6	40,670
22	424	424	Check 22	184.82	284.1	65,496
23	425	425	Check 23	197.05	280.5	64,580
24	426	426	Check 24	207.94	278.3	57,500

<b>Pool No</b>	<b>DSM2 Node</b>	<b>DSM2 Channel</b>	<b>Feature</b>	<b>Mile post</b>	<b>Invert Elev(ft)</b>	<b>Canal length(ft)</b>
25	427	427	Check 25	217.79	278.8	52,001
26	428	428	Check 26	224.92	277.7	37,660
27	429	429	Check 27	231.73	276.4	35,960
28	430	430	Check 28	238.11	276.4	33,700
29	431	431	Check 29	244.54	276.1	33,940
30	433	432-433	Buena Vista Pumping Plant Check 30	250.99	279.5	34,984
31	434	434	Check 31	256.14	476.1	27,281
32	435	435	Check 32 Santiago Creek Siphon	261.72	474.8	29,528
33	436	436	Check 33 San Emigdio Creek Siphon	267.36	473.6	29,901
34	437	437	Check 34 Pleitito Creek Siphon	271.27	469.9	20,557
35	439	439	Teerink Pumping Plant / Check 35	278.13	480.9	37,504
36	440	440	Chrisman Pumping Plant / Check 36	280.36	703.7	12,335
37	441	441	Check 37 Salt Creek Siphon	283.95	1221.1	19,217
38	442	442	Check 38 Grapevine Creek Siphon	287.09	1220.4	16,536
39	443	443	Check 39	290.21	1219.6	16,270
40	444	444	Edmonston Pumping Plant Check 40	293.45	1171.2	25,170
41	447	447	Check 41 Tehachapi Control Structure	303.41	3078	45,047
42	448	448	Check 42	304.99	3077.7	8,200
43	450	450	Check 43	309.7	2945.2	20,975
44	451	451	Check 44	314.81	2943.4	26,990
45	452	452	Check 45	319.74	2941.7	26,000
46	453	453	canal	319.76	2941.6	21,500
47	454	454	Check 47			15,501
48	455	455	Check 48			21,362
49	457	456-457	Check 49	335.93	2934.8	27,103
50	460	458-460	Check 50			29,340
51	461	461	Check 51			2,960
52	462	462	Check 52	343.74	2931.5	8,984
53	464	463-464	Check 53			23,241
54	465	465	Check 54	350.25	2928.2	11,129
55	466	466	Check 55			12,820
56	467	467	Check 56			10,870

<b>Pool No</b>	<b>DSM2 Node</b>	<b>DSM2 Channel</b>	<b>Feature</b>	<b>Mile post</b>	<b>Invert Elev(ft)</b>	<b>Canal length(ft)</b>
57	468	468	Check 57	356.93	2923.7	11,523
58	469	469	Pearblossom Pumping Plant Check 58	360.61	2922	19,424
59	470	470	Check 59			28,810
60	471	471	Check 60	373.94	3458.1	41,792
61	472	472	Check 61	379	3455.9	26,500
62	473	473	Check 62	384.26	3453.4	27,775
63	474	474	Check 63	389.5	3450.8	27,665
64	475	475	canal	389.51	3450.1	29,440
65	476	476	Check 65			27,550
66	477	477	Check 66			16,310
67	478	478	Silverwood Lake	405.94	3305.8	13,307
<b>South Bay Aqueduct</b>						
S1	601	601	Surge Tanks	0.78	728	4,121
S1	602	602	Back Surge Pool	3.26	763.9	13,166
S2	603	603	Dyer Altamont Check Siphon 2	5.21	773.8	3,530
S3	604	604	Highway 580 Tunnel	7.35	705.7	12,250
S3	605	605	Patterson Check 3	9.49	704	10,365
S4	606	606	Lupin Check 4	10.68	702	6,273
S5	607	607	Arroyo Seco Check Siphon 5	12.29	700.3	8,891
S6	608	608	Arroyo Mocho Check Siphon 6	14.65	696	12,987
S7	609	609	Del Valle Check 7	16.38	692.2	8,250
S8	610	610	Del Valle Branch Junction	18.63	475.5	11,860
S8	611	611	La Costa Tunnel	19.96	656.7	12,400
S8	612	612	Mission Tunnel	27.86	593.1	39,810
S8	613	613	Santa Clara Pipeline	35.86	444.4	67,910
S8	614	614	Terminal Pipeline	41.38	186	4,530
			Santa Clara Terminal Reservoir			
<b>West Branch</b>						
W1	701	701	Oso Pumping Plant	1.49	3082.3	8,005
W1	702	702	Quail Lake Inlet 1	4.64	3308.6	16,702
W2	703	703	Quail Lake Outlet	6.07	3288.3	8,091
W2	704	704	Lower Quail Canal	6.21	3286.7	10,760
W2	705	705	Warne Powerplant 2	14.07	2586	30,874

<b>Pool No</b>	<b>DSM2 Node</b>	<b>DSM2 Channel</b>	<b>Feature</b>	<b>Mile post</b>	<b>Invert Elev(ft)</b>	<b>Canal length(ft)</b>
W3	707	706-707	Pyramid Lake	14.1	2555.5	25,300
<b>Delta Mendota Canal</b>						
1	101	101	End of Pipe	3.5	176.83	
1	109	109	Check 1	11.35	174.76	1,448
2	115	115	Check 2	16.19	173.48	3147
3	120	120	Check 3	20.63	172	3443
4	124	124	Check 4	24.43	171.3	5064
5	130	130	Check 5	29.82	169.88	3459
6	240	240	Westley Wasteway			
6	135	135	Check 6	34.42	168.67	1000
7	140	140	Check 7	38.68	167.54	2493
8	146	146	Check 8	44.26	166.07	4462
9	151	151	Check 9	48.62	164.92	3021
10	260	260	Newman Wasteway	54.22	163.44	4571
10	157	157	Check 10	54.41	163.39	1000
11	162	162	Check 11	58.28	162.37	2717
12	169	169	Check 12	63.99	160.86	2574
13	280	280	San Luis (Volta) Wasteway	69.82	159	3013
13	177	177	Check 13	70.01	159.27	1000
14	182	182	Check 14	74.40	158.11	3,179
15	188	188	Check 15	79.64	156.73	2,667
16	194	194	Check 16	85.09	155.29	3776
17	200	200	Check 17	90.54	153.85	3776
18	207	207	Check 18	96.81	152.2	3106
19	216	216	Check 19	105.06	150.02	4003
20	300	300	Firebaugh Wasteway	111.07	148.43	1736
20	223	223	Check 20	111.26	148.38	1000
21	230	230	Check 21	116.48	147	2830

### **1.3 Verification of the DSM2 Aqueduct model**

The calibration of original DSM2 Aqueduct model covered a three-year period starting January 1, 2001. The model was not verified using a separate input set for a time period different from the calibration time period. The original model was calibrated to calculate water velocities, stages of water bodies, and EC, a surrogate for salinity. During the verification and improvement period, the model was verified using 21-year data starting from January 1, 1990. The three-year calibration period was also included in the verification process since data was collected from more sources, more ground water pump-in and storm water inflows were included in the model, and the model experienced some improvement.

The completion of the verification process was a result of team work among three groups in DWR: Operation Control Office (OCO), MWQI program and Bay Delta Office (BDO). OCO was responsible for compiling all the flow and stage data for model verification from different sources. The data includes pumping at major pumping stations which move water into or out of the Aqueduct and DMC, diversions from the California Aqueduct, DMC, or San Luis Reservoir by water contractors, groundwater pump-ins and storm water flow to the modeled system, rainfall and evaporation. MWQI collected EC, DOC and Bromide for the model's boundary inflows from three sources, California Data Exchange Center (CDEC), Water Data Library (WDL), and U.S. Bureau of Reclamation. More details about data compilation will be explained in the next chapter. BDO developed a tool to pre-process hydro and water quality data for the DSM2 Aqueduct model. The main tasks that the tool can accomplish include (1) downloading data from CDEC; (2) converting monthly data to daily data required by the model; (3) conducting calculation of mass balance; (4) filling missing EC and DOC data; (5) calculating Bromide from EC and fingerprinting data; and (6) exporting data to DSS files.

### **1.4 The DSM2 Version 8 (v8)**

DSM2 v8 is an improvement on DSM2 version 6. Several bugs found in version 6 were fixed. Two main enhancements to DSM2 are (1) some algorithms were changed to speed up the program run, and (2) operating rules were introduced in version 8 so gates / barriers can operate according to specified operating rules. No significant difference can be observed when model results from running two versions of DELTA DSM2 model were compared. The verification for the DSM2 Aqueduct model was also done using DSM2 version 8. Results for flows, stages, EC, Bromide and DOC from both version 6 and version 8 DSM2 Aqueduct models were compared, and no significant differences were observed. For the current version 8 of the DSM2 Aqueduct model, gate operations are treated the same way as in version 6 of the model. BDO has spent limited time on trying to use operation rules for gate operations, but without luck. The problem is that the model would not converge for most of the time steps, thus the results cannot be trusted. This issue will be investigated in more detail in the future.

## **2. Hydrologic and Water quality data**

The DSM2 extension model is driven by a lot of data, which include both hydrologic and water quality data. For the HYDRO part of the extension model, O&M compiled hydrologic data from various sources, and did analysis on gains and losses. MWQI compiled water quality data for the QUAL part of the extension model. The following several sections will cover work done by O&M and MWQI in more details.

### **2.1 Hydrologic data**

For the HYDRO part of the DSM2 extension model, several types of data have to be given. Among them are (1) pumping flows or Check flows, (2) meteorological data (rainfall and evaporation), (3) groundwater inflows, (4) storm water inflows, (5) diversion flows, and (6) storage changes of the Aqueduct. For the 21-year simulation period starting from January 1, 2010, O&M compiled data from different sources. Table 2-1 is a list of the data sources for the historical data and current data.

The pumping flows at Banks and Jones Pumping plants are treated as boundary inflows in the model. The pumping flows at South Bay Pumping Plant, Oso Pumping Plant, the Las Perillas Pumping Plant, Dos Amigos pumping Plant, pumping/generating flow for Gianelli Generating Plant and O'Neill Generating Plant are treated as object-to-object flow transfer. Daily delivery data for the Pacheco Tunnel is treated as a San Luis Reservoir diversion. Flows at SWP Check 21, pumping flows at Edmonston and Pearblossom Pumping Plants were not directly used in the model, instead, they were used in mass balance calculations, which will be discussed in the next section.

Meteorological data is mainly used as inflows / outflows for San Luis Reservoir. Groundwater and storm water inflows are grouped by pool along the Aqueduct or DMC (Tables 2-2 and 2-3). Monthly delivery data for each diversion are grouped by pool along the Aqueduct or DMC. Because some pools are modeled with multiple channels, all diversions within a pool are aggregated and withdrawn at the node corresponding with the pool's downstream check. Major diversions, such as wasteways on the DMC, are included as separate nodes at their actual physical location (Tables 2-4 and 2-5).

**Table 2-1. Sources for hydrologic data**

<b>Data</b>	<b>Historical</b>	<b>Current</b>
Evaporation / Precipitation at SWP& DMC	CIMIS <a href="http://www.cimis.water.ca.gov/cimis/welcome.jsp">http://www.cimis.water.ca.gov/cimis/welcome.jsp</a>	CIMIS <a href="http://www.cimis.water.ca.gov/cimis/welcome.jsp">http://www.cimis.water.ca.gov/cimis/welcome.jsp</a>
Evaporation / Precipitation at San Luis	Prior to 1998, SWP Monthly Operations Data Reports <a href="http://www.water.ca.gov/swp/operationscontrol/monthly.cfm">http://www.water.ca.gov/swp/operationscontrol/monthly.cfm</a>	CVP Reservoir Operations Reports <a href="http://www.usbr.gov/mp/cvo/reports.html">http://www.usbr.gov/mp/cvo/reports.html</a>
Pumping data	MAPPER*	MAPPER*
Pacheco Tunnel and Check 21 Flows	MAPPER*	MAPPER*
Diversion and Pump-in Flows for the SWP	Prior to 2000, SWP Monthly Operations Data Reports / SWP Annual Reports of Operation <a href="http://www.water.ca.gov/swp/operationscontrol/monthly.cfm">http://www.water.ca.gov/swp/operationscontrol/monthly.cfm</a> <a href="http://www.water.ca.gov/swp/operationscontrol/annual.cfm">http://www.water.ca.gov/swp/operationscontrol/annual.cfm</a>	SAP*
Diversion and Pump-in Flows for the DMC	San Luis-Delta-Mendota Water Authority	San Luis-Delta-Mendota Water Authority

\* For information about MAPPER or SAP data please contact the Delta Compliance and Modeling Section ([dcm@water.ca.gov](mailto:dcm@water.ca.gov)) or the Operations Records and Reports Section ([ocoweb@water.ca.gov](mailto:ocoweb@water.ca.gov))

**Table 2-2. Sources and DSM2 Nodes in the SWP**

	<b>Pool</b>	<b>DSM2 Node</b>	<b>Source Agency</b>
<b>Groundwater</b>			
		408	Turlock Fruit Company
	13	415	SLWD
	15	417	WWD
	16	418	WWD
	17	419	WWD
	18	420	WWD
	19	421	WWD
	20	422	WWD
	21	423	WWD
	24	426	KCWA
	25	427	Semitropic (KCWA)
		429	KCWA
	28	430	Cross Valley (KCWA)
	29	431	KCWA West Kern
		436	WRMWSD
		437	WRMWSD
	35	439	Arvin Edision
<b>River Water</b>			
		418	Non specific flood water
		419	Non specific flood water
	18	420	Salt creek
		421	Non specific flood water
	18	420	Cantua Creek
	20	422	Arroyo Pasajero
		423	Non specific flood water
	29	431	Kern River Intertie

**Table 2-3. Sources and DSM2 Nodes in the DMC**

Mile	Pool	DSM2 Node	Source Agency
<b>Groundwater</b>			
12.75, 15.11	2	115	BCID
14.26	2	115	BBID
21.25,23.41	4	124	DPWD
30.43-33.71	6	135	DPWD
35.73-37.32	7	140	DPWD
		151	Sunflower Discontinued
48.97	10	157	SLWD
49.54,51.66	10	157	DPWD
58.28	12	169	SLWD
58.73	12	169	DPWD
		177	Quinto Discontinued
78.31	15	188	PANOCHÉ
79.13	15	188	SLWD
79.6	16	194	SLWD
80.03	16	194	PANOCHÉ
		200	San Luis Discontinued
		207	Panoche Discontinued
98.74	19	216	PANOCHÉ/MS
99.24	20	223	PANOCHÉ/MS
		230	San Luis Discontinued
<b>River water</b>			
3.32	1	109	BBID
20.42	3	120	BCID
31.31	6	135	WSTAN
42.53	8	146	PID

**Table 2-4. Diversions and DSM2 Nodes in the California Aqueduct and South Bay Aqueduct**

<b>Mile</b>	<b>Pool</b>	<b>DSM2 Node</b>	<b>Diversions Agency</b>
4.49	1	402	Bethany Reservoir Inlet
5.95	1	402	South Bay Aqueduct
8	2	403	Mountain House Golf Course
12.47	3	404	Musco Olive
22.16	4	405	Tracy Golf & Country Club
35.22	7	408	Turlock Fruit Company Inflow
42.9	8	409	Western Hills WD
	8	409	Oak Flat Water District - total
46.18	9	410	Oak Flat Water District-D
66.14	12	413	Veteran's Cemetery
66.14	12	413	Merced Irrigation District
70.85	13	415	Department of Parks and Recreation
70.85	13	415	Cattle Program
70.85	13	415	Department of Fish & Game
85.08	13	415	San Luis Water District
85.08	13	415	(Floodwater Inflow)
SL Res	13	415	Department of Parks and Recreation
	13	415	San Felipe Division - total
89.67	14	416	Pacheco Water District
89.68	14	416	Panoche Water District
89.7	14	416	City of Dos Palos
94.06	14	416	San Luis Water District
102.64	15	417	Panoche Water District
102.64	15	417	(Floodwater Inflow)
102.64	15	417	Broadview Water District
104.2	15	417	San Luis Water District
122.05	16	418	(Reverse flow, Kings River)
122.05	16	418	Department of Fish and Game
	16	418	Westlands Water District - total
132.74	17	419	Floodwater Inflow
132.74	17	419	Westlands Water District
142.61	18	420	(Floodwater Inflow)

<b>Mile</b>	<b>Pool</b>	<b>DSM2 Node</b>	<b>Diversion Agency</b>
4.49	1	402	Bethany Reservoir Inlet
5.95	1	402	South Bay Aqueduct
8	2	403	Mountain House Golf Course
12.47	3	404	Musco Olive
22.16	4	405	Tracy Golf & Country Club
35.22	7	408	Turlock Fruit Company Inflow
143.16	18	420	City of Coalinga
	18	420	Westlands Water District - total
151.19	19	421	Westlands Water District
151.19	19	421	(Floodwater Inflow)
151.19	19	421	City of Huron Parks & Recreation
156.34	19	421	Garrett Wheeladartor Frye Energy Company
156.34	20	422	City of Huron
163.69	20	422	Westlands Water District
164.79	21	423	City of Avenal
171.67	21	423	Westlands Water District
171.67	21	423	(Floodwater Inflow)
184.63	22	424	Coastal Branch
184.78	22	424	DRWD (aggregated)
	22	424	TLB WSD - total
	23	425	KCWA - total
	24	426	KCWA - total
209.71	25	427	USBR ST Pen
	25	427	KCWA - total
	25	427	Kern National Wildlife - total
	26	428	KCWA - total
230.37	27	429	Kern County Water Agency Buena Vista - 6
238.04	28	430	Tulare Co.
238.04	28	430	Kern Tulare
238.04	28	430	Rag Gulch
238.04	28	430	Hills Valley
238.04	28	430	Tri Valley

<b>Mile</b>	<b>Pool</b>	<b>DSM2 Node</b>	<b>Diversion Agency</b>
4.49	1	402	Bethany Reservoir Inlet
5.95	1	402	South Bay Aqueduct
8	2	403	Mountain House Golf Course
12.47	3	404	Musco Olive
22.16	4	405	Tracy Golf & Country Club
35.22	7	408	Turlock Fruit Company Inflow
238.04	28	430	Hacienda DWR Wells
238.04	28	430	DRWD CVC
238.04	28	430	Arvin Edison WD CVC
238.04	28	430	Friant Water Users Authority
238.04	28	430	Lower Tule River
238.04	28	430	Fresno Co.
238.04	28	430	Pixley ID
	28	430	KCWA - total
241.02	29	431	Kern River Intertie (inflow)
244.54	29	431	Buena Vista WSD
	29	431	KCWA - total
	29	431	Kern Water Bank (in - out)
249.85	30	433	Kern County Water Agency Buena Vista - 4
	31	434	KCWA - total
	32	435	KCWA - total
	33	436	KCWA - total
270.24	34	437	Kern County Water Agency Wheeler Ridge-Maricopa - 7
277.31	35	439	KCWA Arvin-Edison
	35	439	KCWA - total
	36	440	KCWA - total
282.06	37	441	Kern County Water Agency Wheeler Ridge-Maricopa - 12
	38	442	KCWA - total
287.62	39	443	Kern County Water Agency Wheeler Ridge-Maricopa - 14
	40	444	KCWA - total

<b>Mile</b>	<b>Pool</b>	<b>DSM2 Node</b>	<b>Diversion Agency</b>
4.49	1	402	Bethany Reservoir Inlet
5.95	1	402	South Bay Aqueduct
8	2	403	Mountain House Golf Course
12.47	3	404	Musco Olive
22.16	4	405	Tracy Golf & Country Club
35.22	7	408	Turlock Fruit Company Inflow
298.65	41	446	Kern County Water Agency Tej.-Cas
305.73	43	450	Alama Power Plant (Cottonwood Chutes)
308.05	43	450	Antelope Valley-East Kern WA
311.84	44	451	LADWP Connection
313.5	44	451	AVEK 245th Street West
	45	452	AVEK WA - total
323.19	46	453	Mojave Water Agency Fairmont
	46	453	AVEK WA - total
	48	455	AVEK WA - total
	50	460	AVEK WA - total
	52	462	AVEK WA - total
346.98	53	464	Palmdale
348.14	53	464	Antelope Valley-East Kern WA Acton Treatment Plant
354.97	57	468	Littlerock Creek I.D.
	58	469	AVEK WA - total
366.5	60	471	Antelope Valley-East Kern WA
389.2	63	474	Mojave Water Agency Mojave River
394.6	64	475	Mojave Water Agency Temporary
	66	477	Mojave Water Agency - total
405.48	67		Las Flores Ranch

Mile	Pool	DSM2 Node	Diversion Agency
4.49	1	402	Bethany Reservoir Inlet
5.95	1	402	South Bay Aqueduct
8	2	403	Mountain House Golf Course
12.47	3	404	Musco Olive
22.16	4	405	Tracy Golf & Country Club
35.22	7	408	Turlock Fruit Company Inflow
405.65	67		Mojave Power Plant
405.65	67		(Does not include 7,713 AF of Bypass flow)
405.7	67		Mojave Water Agency
407.65	67		Crestline Lake Arrowhead Water Agency
407.65	67		Mojave Water Agency Outlet Works
407.65	67		Calif. State Park Silverwood Agency (Rec.)
	67		Mojave Water Agency
0	1	601	(into South Bay Aqueduct)
3.17	1	601	Granite - Vasco Rd. (Temp.)
3.18	1	601	Oakland Scavenger Zone 7
7.21	3	603	Zone 7 Altamont
9.49	3	603	Zone 7 Patterson (aggregated)
13.55	6	605	DeSilva-Gates (Temp)
13.55	6	605	Zone 7 Wentle #1
14.16	6	605	Zone 7 Wentle #2
14.31	6	605	Zone 7 Ising (Temporary)
14.31	6	605	Ising Inflow Exchange
14.31	6	605	Ising Project Water
	7	608	Zone 7 Arroyo Mocho - total
16.57	8	609	Zone 7 Wentle #3
16.69	8	609	Zone 7 Norman Nursery
16.7	8	609	Zone 7 Concannon
16.7	8	609	Zone 7 Wentle #4
18.63	8	609	(Flow out of South Bay Aqueduct)
18.63	8	609	(Flow into South Bay Aqueduct)
19.2	8	609	Del Valle Branch Pipeline (aggregated)
19.2	8	609	So. Livermore (aggregated)
19.21	8	609	Zone 7 - Kalthroff Detjens
35.86	8	609	S.C.V.W.D. Meter
	8	609	ACWD - total
		609	City of San Francisco - total

<b>Mile</b>	<b>Pool</b>	<b>DSM2 Node</b>	<b>Diversion Agency</b>
4.49	1	402	Bethany Reservoir Inlet
5.95	1	402	South Bay Aqueduct
8	2	403	Mountain House Golf Course
12.47	3	404	Musco Olive
22.16	4	405	Tracy Golf & Country Club
35.22	7	408	Turlock Fruit Company Inflow
8	W2		AVEK Water Agency
Pyr Lake	W3		Calif. State Park Pyramid Recreation
14.1	W3		United Water Conservation Dist.
17.1	W3		Piru Creek Fish Enhancement

**Table 2-5. Diversions and DSM2 Nodes in the DMC**

<b>Mile</b>	<b>Pool</b>	<b>DSM2 Node</b>	<b>Diversion Agency</b>
7.7	1	109	DWR Intertie @MP7.70-R
8.51	1	109	West Side ID
8.71-11.28	1	109	Byron Bythany WD
11.45-15.1	2	115	Byron Bythany WD
15.85	2	115	Tracy, City of
16.64-19.59	3	120	Byron Bythany WD
18.05-20.59	3	120	Del Puerto WD
20.42	3	120	Banta Carbona ID
20.97	4	124	Byron Bythany WD
21.12-24.38	4	124	Del Puerto WD
25.02-29.56	5	130	Del Puerto WD
29.95-34.08	6	135	Del Puerto WD
31.31	6	135	W. Stanislaus ID
34.55-38.15	7	140	Del Puerto WD
38.8-44.24	8	146	Del Puerto WD
42.51	8	146	Patterson WD
45.2-48.6	9	151	Del Puerto WD
48.96-54.01	10	157	Del Puerto WD
54.7-58.26	11	162	Del Puerto WD
58.27-60.65	12	169	CCID (Abv CK 13)
58.73-63.96	12	169	Del Puerto WD
64.32-68.03	13	177	Del Puerto WD
66.2	13	177	Centinella WD
69.21	13	177	San Luis WD - M&I
69.98	14	182	Volta Wildlife Mgmt Area (F&G)
69.98	14	182	Grasslands WD - Volta
69.98	14	182	F&S (Volta) Santa Fee Kest.
72.34,73.06	14	182	San Luis WD - Ag
76.05	15	188	Frietas Unit (76.05L)
76.05	15	188	China Island (76.05)
76.05	15	188	CCID (Blw CK 13)
76.05	15	188	F&S - Kesterson 76.05L

Mile	Pool	DSM2 Node	Diversion Agency
7.7	1	109	DWR Intertie @MP7.70-R
8.51	1	109	West Side ID
8.71-11.28	1	109	Byron Bythany WD
11.45-15.1	2	115	Byron Bythany WD
15.85	2	115	Tracy, City of
16.64-19.59	3	120	Byron Bythany WD
18.05-20.59	3	120	Del Puerto WD
20.42	3	120	Banta Carbona ID
76.05	15	188	F&G - Los Banos Ref. 76.05L
76.05	15	188	Grasslands WD -76.05L
76.05	15	188	Salt Slough Unit (76.05L)
76.77-79.13	15	188	San Luis WD - Ag
80.99-83.08	16	194	San Luis WD - Ag
83.08	16	194	CCID (Blw CK 13)
85.05-90.53	17	200	CCID (Blw CK 13)
86.71-90.53	17	200	San Luis WD - Ag
90.57	18	207	CCID (Blw CK 13)
90.57	18	207	San Luis WD - Ag
93.27,93.57	18	207	Eagle Field WD
95.5-96.62	18	207	Oro Loma WD
93.25	18	207	Panoche WD - Ag
95.95	18	207	Panoche WD - M&I
96.7	19	216	Panoche WD - Ag
97.7,98.74	19	216	Mercy Springs WD
100.8	20	223	Panoche WD - Ag
102.04	20	223	Widren
100.84	20	223	Panoche WD - M&I
105.05-109.45	20	223	Firebaugh Canal

## 2.2 Gains / losses

When the extension model was developed by CH2MHILL in 2005, it was found that gains / losses must be considered on specific sections of the Aqueduct system in order for the model to run successfully. The gains / losses were the amount of water that cannot be balanced when known outflows and storage change are deducted from known inflows (Equation 2-1).

$$\text{gains / losses} = \text{inflows} - \text{outflows} - \text{storage change} \quad (2-1)$$

Following the similar procedures documented in CH2MHILL's report, gains/losses were calculated using Equation 2-1 for four sections along the Aqueduct main stem (Pools 1 through 67). These four sections are defined as follows:

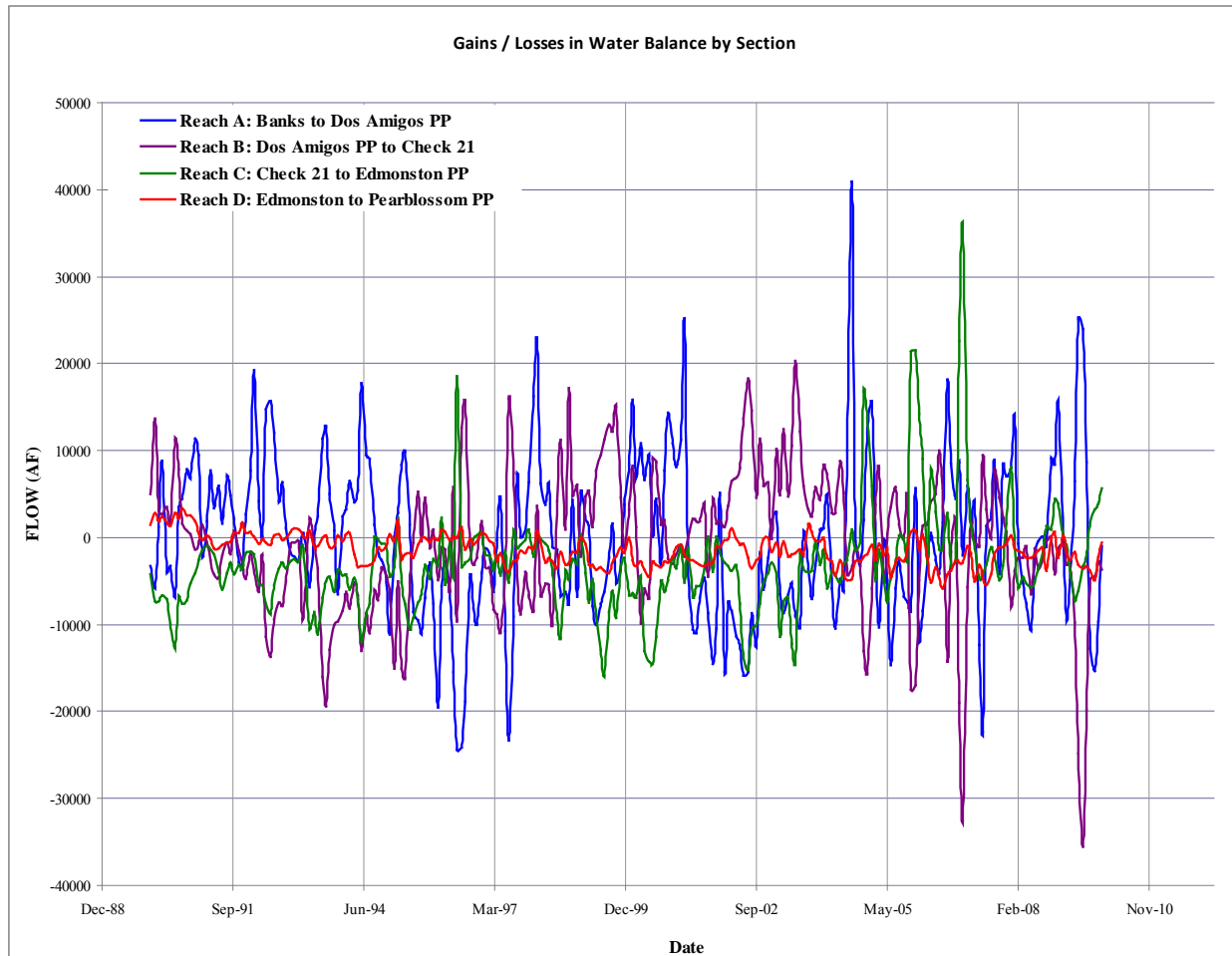
- **Reach A** runs from pool 1 through Dos Amigos Pumping Plant using Banks Pumping Plant flow as the inflow and Dos Amigos flow as the outflow
- **Reach B** starts in pool 14 and runs through Check 21 using Dos Amigos flow as the inflow and Check 21 flow as the outflow
- **Reach C** starts in pool 22 and runs through Edmonston Pumping Plant (Check 40), using Check 21 flow as the inflow and Edmonston flow as the outflow
- **Reach D** starts in pool 41 and runs through Pearblossom Pumping Plant (Check 58), using Edmonston flow as the inflow and Pearblossom flow as the outflow

For Reach A, other major inflows include water released to O'Neill Forebay from San Luis Reservoir, water pumped to O'Neil Forebay from DMC, and groundwater pump-ins. Other major outflows include water pumped to San Luis Reservoir from O'Neill Forebay, water released to DMC from O'Neill Forebay, and water delivered to contractors between DSM2 node 401 and 415. For Reaches B and C, other major flows include groundwater pump-ins and storm water flows. Other major outflows include water delivered to contractors. There is no other major inflows for Reach D. Other major outflows include water delivered to contractors between DSM2 node 445 and 469, which include water delivered to West Branch.

A lot of factors can cause gains / losses. Inaccurate measurements may result in inflows/outflows being higher or lower than actual values. Because seepage and evaporation along the canal are not explicitly measured, they are not included in outflows. At times, high flows overshoot, and excess water flows into SWP or DMC. Since the amount is not known, it is not considered in inflows. Also not considered in inflows is rainfall added to water bodies in the system. Another factor is that both daily and monthly data are used in mass balance calculations. Monthly data such as diversions, groundwater pump-ins, storm water inflows, and storage change were assumed to be a constant flow rate for the month. It is possible that there may be significant weekly or daily variation in the actual inflows/outflows that are not represented in the monthly values.

Figure2-1 presents the results of the mass balance calculations for the four sections of the main Aqueduct. The magnitude of gains / losses in the first two reaches is higher than the magnitude of gains / losses in the last two reaches. There are no distinct seasonal patterns in the gains / losses. No single factor is solely responsible for the spatially and temporally variation of gains / losses. At first sight, the magnitude of gains / losses is significant, but in fact, it is negligible when compared with primary inflows. To further verify that the gains / losses do exist, Bryant Giorgi of O&M compared his calculation with that of Guy Myser and found that both calculations lead to very close results. The minor differences are results that the same data from different sources may be somewhat different.

**Figure 2-1.** Comparison of gains / losses in Water Balance Calculations for Each Section



When CH2MHILL developed the model, closure terms to correct gains / losses were applied in the model at either the upstream or downstream node of each of the four sections. If there is a loss for a reach at any time, an additional inflow was added at the most upstream node of that reach. However, if there is a gain for a reach at any time an additional diversion was added at the farthest downstream node of the reach. Generally there is no problem with this approach except in case losses are significant. For a loss, an additional inflow is added to prevent the channel from drying out. For water quality modeling, the water quality for the inflow must be given at each time step. While this is not a problem for Reach A, it is a problem for Reaches B and D since water quality in those reaches is not known until a model is run. In our approach, when there is a loss in Reach B, C or D, the loss is deducted proportionally from diversions in that reach to keep mass balanced. So there is no need to specify water quality for inflows used to balance losses. For a gain, it is treated the same way as in the CH2MHILL report.

## 2.3 Water quality data

In the water quality model (QUAL), all model inflows require specification of the daily water quality of the inflow. Even though the model requires daily input, for inflows such as groundwater pump-ins and storm water flows only several grab sample data is available. In this case, constant water quality values were assigned to each location using the data provided to BDO by MWQI.

MWQI worked on several tasks to compile EC, Bromide and DOC data from different sources, conducted QA/QC for the data and filled in missing data using linear interpolation when data gaps are less than two months. Water quality data collected by MWQI consists of two parts. Water quality data of inflows was used in the model. The left was used to verify the model. The Metropolitan Water District of Southern California also provided Bromide and DOC data for model verification. The following several paragraphs give more details about how data was collected and processed.

The EC data for the CA Aqueduct and DMC was analyzed using Standard Methods 2510-B (Fong and Aylesworth 2006, Clesceri *et al.* 1998) and EPA Method 120.1 (USEPA 2000). MWQI collected EC data for both surface water inflows and groundwater pump-ins.

Conductivity measurements were taken from 95 stations in the CA Aqueduct. When available, real time data from the California Data Exchange Center (CDEC) was used. When real-time data was not available, grab sample data from the Water Data Library (WDL) was used.

At some stations, salts were measured as Total Dissolved Solids (TDS) instead of EC. In order to convert these measurements to EC, data from the two closest stations with complete EC and TDS datasets were identified. A Mann-Whitney test was used to determine if EC at these 2 stations were similar. If there were no statistical differences, then a regression equation between EC and TDS was derived at one station. Since EC was statistically similar between the 2 stations, it was assumed that the EC-TDS relationship would also be similar for the stations bounded by the stations with the complete datasets and that the same TDS-EC regression line could be used to calculate EC measurements from TDS data.

For example, in the CA Aqueduct, TDS was measured instead of EC at the Arvin Edison Pump-in, Kern, Semitropic 2, Semitropic 3, and Cross Valley Canal stations. Checks 21 and 29 bounded these stations and also had a full complement of TDS and EC data. Since there was no statistical difference in EC between these 2 stations ( $p\text{-value} = 0.000$ ), a regression equation was developed between TDS and EC data using data from Check 29. This regression equation was used to develop EC values for all stations (including pump-in locations) bounded between these 2 check stations. Discussions with Department groundwater specialists determined that the assumptions used for surface water could be applied to groundwater situations. Therefore, transformation of groundwater TDS to EC used the regression equation described above for groundwater pump-ins bounded by Checks 21 and 29.

Conductivity measurements were taken at 59 stations in the DMC. The data for the DMC analyses came from several different sources. When available, daily and hourly data was retrieved from CDEC. Water quality, including both Central Valley Project (CVP) and non CVP data, was provided by the USBR database (USBR 2009). Data for wells pumping groundwater into the DMC between Check 13 and Check 21 data were obtained from a spreadsheet provided to us by USBR personnel.

Bromide measurements were taken at 79 stations in the CA Aqueduct. When available, real time data from the California Data Exchange Center (CDEC) was used. When real-time data was not available, grab sample data from the Water Data Library (WDL) was used. Bromide measurements were taken at 9 stations in the DMC. The data for the DMC analyses came from several different sources. When

available, daily and hourly data was retrieved from CDEC. Water quality, including both Central Valley Project (CVP) and non CVP data, was provided by the USBR database (USBR 2009). Data for wells pumping groundwater into the DMC between Check 13 and Check 21 data were obtained from a spreadsheet provided to us by USBR personnel.

The DOC data for the CA Aqueduct and DMC was analyzed using either the combustion method (EPA Methods 415.1) or the oxidation method (EPA Method 415.3) (USEPA 1999 and USEPA 2005). Both methods are considered equivalent by the EPA for measuring DOC. Generally, variability between the 2 methods occurs with measurements of the total organic carbon fraction, not the dissolved fraction; therefore, combining the DOC data generated by these 2 methodologies was considered acceptable for this report.

DOC measurements were taken at 91 stations in the CA Aqueduct. When available, real time data from the California Data Exchange Center (CDEC) was used. When real-time data was not available, grab sample data from the Water Data Library (WDL) was used.

At some stations, carbon was measured as Total Organic Carbon (TOC) instead of Dissolved Organic Carbon (DOC). In order to convert these measurements to DOC, data from the two closest stations with complete TOC and DOC datasets were identified. A Mann-Whitney test was used to determine if DOC at these 2 stations were similar. If there were no statistical differences, then a regression equation between DOC and TOC was calculated at one of these stations. Since DOC was statistically similar between the 2 stations, it was assumed that the DOC-TOC relationship would also be similar for the stations bounded by the stations with the complete datasets and that the same DOC-TOC regression line could be used to calculate TOC measurements from a station's DOC data.

DOC measurements were taken at 9 stations in the DMC. The data for the DMC analyses came from several different sources. Water quality, including both Central Valley Project (CVP) and non CVP data, was provided by the USBR database (USBR 2009). Data for wells pumping groundwater into the DMC between Check 13 and Check 21 data were obtained from a spreadsheet provided to us by USBR personnel.

At the station DMC@McCabe Road Near Check 12 (WDL, station ID: DMC06716), carbon was measured as TOC instead of DOC for 27 of the 80 samples. Normally, in order to convert these measurements to DOC, data from the two closest stations with complete TOC and DOC datasets are identified, and a Mann-Whitney test is used to determine if DOC at these 2 stations were similar. However, only the station Delta Mendota Canal at mi 67.15 has enough DOC and TOC measurements to be compared. Therefore, a regression equation between DOC and TOC was calculated for the station Delta Mendota Canal at mi 67.15 without a Mann-Whitney test. The linear correlation coefficient for DOC and TOC was 0.963.

Compared to other inflows, pumping from Banks and Jones PP has more influence on the water quality downstream the Aqueduct. From Table 2-6 it can be seen that water quality data at Banks and Jones PP may have gaps for a long period. A tool, which will be covered in the next chapter, was developed to fill in those gaps in a most reasonable way. For example, there exists no DOC data at Banks PP before 10/23/2003 and at Jones PP before 2/25/2009, and no EC data at Jones PP before 8/24/1999. In this case, EC and DOC outputs from Delta DSM2 Model were used to fill in the gaps. For other EC and DOC gaps that last more than a week, EC and DOC outputs from Delta DSM2 model were not directly used, instead EC and DOC output were adjusted so that the first data just before a gap and the first data just after a gap are the same as measured data of the same day. Data gaps for Bromide were filled in a similar way. The only difference is that at present Delta DSM2 Model does not simulate Bromide, so there exists no direct output for Bromide. The tool used an expression which will be covered in the next chapter to calculate

Bromide from EC (measured or DSM2 calculated) and Martinez fingerprinting at Banks or Jones PP. More details will be covered in the next chapter.

Table 2-6. Available EC, DOC and Bromide Data from CDEC

Station	Constituent	Duration	Data Available
Banks PP	EC	daily	01/01/1986 to present
	DOC	daily	10/23/2003 to present.
	Bromide	daily	01/29/2009 to 02/07/2011
	Bromide	event	10/25/2007 to present
Jones PP	EC	daily	08/24/1999 to present
	EC	hourly	03/31/1988 to present
	DOC	daily	02/25/2009 to present
	Bromide	event	03/05/2011 to present

### 3. Implementing Model for Historical Simulation

It's a very time consuming process to pre-process all input data for the extension model. A tool based on Microsoft Excel VBA was developed to save time, and reduce possible mistakes when many raw data are processed for use in the DSM2 Aqueduct model. The tool includes one interface (Fig 3.1) and some EXCEL worksheets. On the interface are EXCEL cells for data input, tabs for worksheets for storing raw and processed data, buttons for executing the 8 steps for pre-processing input data, running the DSM2 Aqueduct model, and post-processing model results.

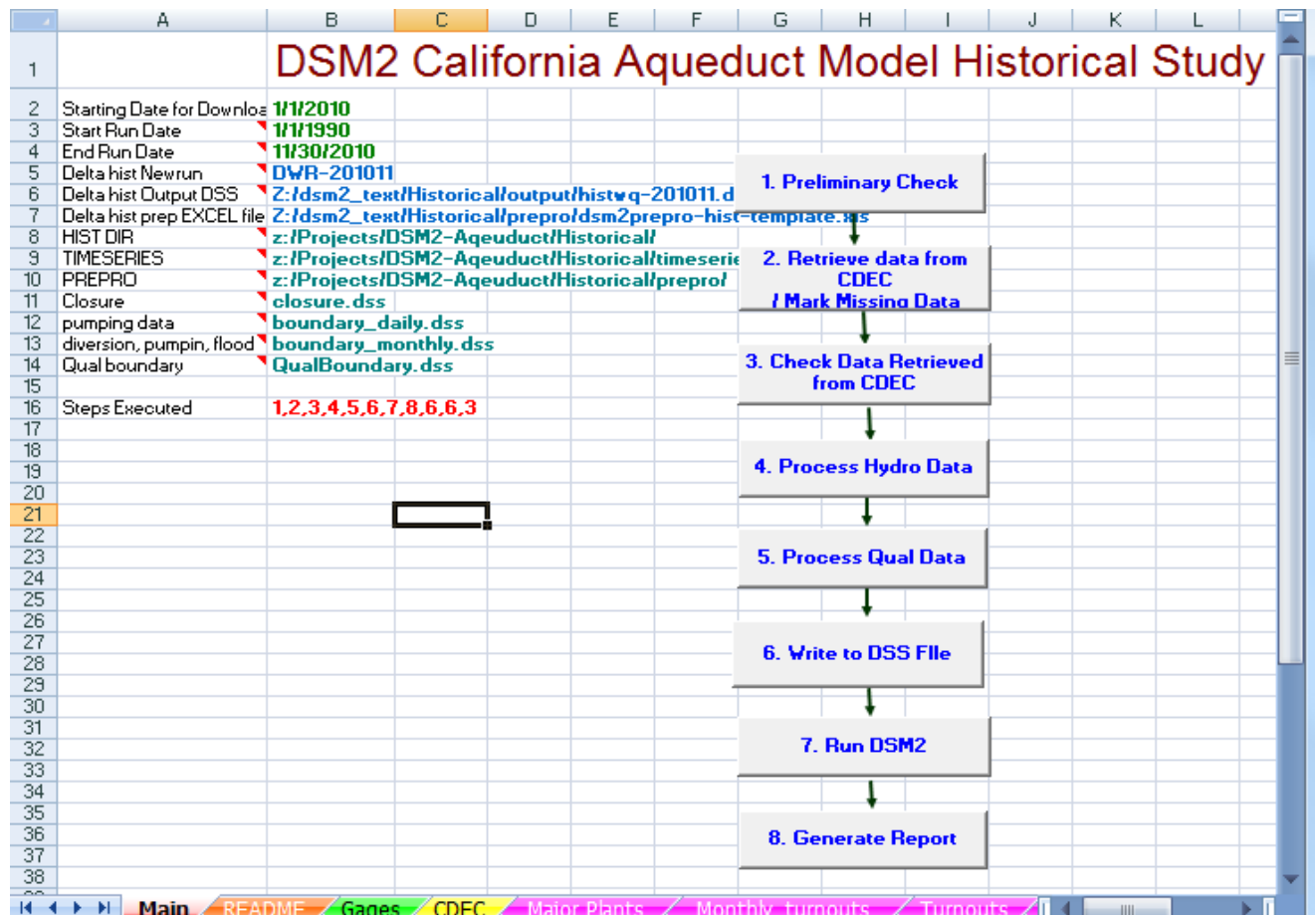


Fig. 3.1 Interface of the tool for pre-processing raw data for use in the DSM2 Aqueduct model

Tasks that can be completed by using the tools include: (1) downloading water quality data from CDEC; (2) pre-processing hydraulic and water quality data; (3) calculating water gains / losses for the Aqueduct system.; (4) exporting data to DSS file for use by the DSM2extension model; (5) executing the DSM2 Aqueduct model; and (6) post-processing model results. The more detailed descriptions of each task are included in the following paragraphs.

### 3.1 Download of water quality data from CDEC

For the two components of the DSM2 Aqueduct model, historical hydraulic and water quality data must be provided in right format. For the present, O&M staff compiled hydraulic data from different sources, and put them on seven EXCEL worksheets according to seven classifications,

- Flows from pumping plants;
- Diversions by SWP and CVP contractors;
- Groundwater pumping into the Aqueduct and DMC;
- Storm water inflows to the Aqueduct and DMC;
- Evaporation from the San Luis Reservoir, the Aqueduct and DMC;
- Rainfall to the San Luis Reservoir, the Aqueduct and DMC, and
- Storage changes for the four sections of the California Aqueduct.

There are two kinds of water quality data, time-series data and data with constant values. The water quality data for groundwater pump-in and storm water belong to the second case, and their values will not change with time unless in the future more grab sampled water quality are available. Water quality data at Bank and Jones Pumping Plants, some checks and San Luis Reservoir are available from CDEC. Table 3.1 lists the CDEC stations and the availability of water quality data for each station.

Table 3.1 Availability of water quality data

<b>CDEC Station</b>	<b>Station ID</b>	<b>EC(us/cm)</b>	<b>Bromide (mg/l)</b>	<b>DOC (mg/l)</b>
Banks Pumping Plant	HBP	01/01/1986 to present.	01/29/2009 to 02/07/2011	01/29/2009 to 02/07/2011
Banks Pumping Plant	HRO		10/25/2007 to present ( <b>event</b> )	10/23/2003 to present
Clifton Court Forebay	CLC	01/01/1987 to present		
DMC Headworks	DMC	08/24/1999 to present		
Jones Pumping Plant	TRP		03/05/2011 to present ( <b>event</b> )	02/25/2009 to present
Pacheco Pumping Plant	PPP	07/03/1989 to present.	01/29/2009 to 02/07/2011	
Check 12	C12	01/01/1990 to 08/19/2002		
Check 13	C13	01/01/1990 to present	01/29/2009 to 02/07/2011	01/29/2009 to 02/07/2011
Check 18	C18	06/01/1990 to 08/14/2002		
Check 21	C21	06/01/1990 to present		
Check 29	C29	01/01/1990 to present.	01/29/2009 to 02/07/2011	
Check 41	C41	06/01/1993 to present	01/29/2009 to 02/02/2011	
Check 66	C66	07/15/2003 to present		
DMC Check 20	DM2	08/24/1999 to		

		present		
DMC Check 21	DM3	08/24/1999 to present		
Del Valle Check 7	DV7	06/08/1994 to present		

Since DSM2 model only uses daily data, downloaded event data at Banks (HRO) and Jones (TRP) Pumping plants must be converted to daily data. This can be accomplished by using the tool.

### 3.2 Check downloaded data

Data downloaded from CDEC may have some problems. The user can use the tool to select time-series plots for each station from a list of stations. The tool does not have the capability to automatically mark problematic data, instead the user is responsible for determining data with problem, and removing them. In case that the time-series may be very long, and it is difficult to locate the data with problem, the user can click the data with mouse on the time-series plot, the tool will put focus on the data with problem.

### 3.3 Pre-process of hydraulic data and mass balance calculations

Hydraulic data must be pre-processed for several purposes. Monthly data such as storage changes and diversions by water contractors must be converted to daily data for the model to use. This was done by assuming constant values for the month. Some daily flow data was averaged on seven-day basis for mass balance calculations and also for the model to use, an approach documented in CH2MHILL's report. The purpose of the approach is to remove unrealistic short-term spikes in the simulated flows. Another purpose of the pre-process is to perform mass balance calculations and calculate gains and losses. In consistent with the work done by CH2MHILL's report, mass balance calculations are conducted to find gains / losses for the four sections along the California Aqueduct main stem. Gains and losses are the flow amount that cannot be balanced when available inflows to, outflows from, and storage change of a section are considered.

The reasons for the imbalance include evaporation, rainfall to water bodies, seepage loss, meter errors, and etc. Another reason is that mass balance is conducted on daily basis, while a lot of data was collected on monthly basis. For example, terms such as storage change and diversions are assumed to be a constant value for a month. It is possible that there may be significant weekly or daily variation in the actual diversions that is not represented in the monthly values. So the result may be in some days too much water was diverted, while other days too little water was diverted when compared with actual diversions. Those discrepancies are also reflected in the gains / losses in mass balance calculations.

The tool automates the calculations of mass balance for the four sections along the main California Aqueduct stem, and stores gains / losses for each section to two time-series, one for gains, another one for losses. In CH2MHILL's report, the time-series for gains was treated as an inflow boundary for the DSM2 Aqueduct model. However, the problem is how to get or assume water quality data for the inflows, especially for the last three sections? In this tool, the gains will be used to adjust total diversions for each section. This makes sense for the reason mentioned in the previous paragraph. Since there is more than one diversion for each section, the adjustment will be divided among all diversions according to the proportion of each diversion in the total diversions for each section. In very rare case that gains may be more than total diversions in a day for a section, the differences will be stored and used for next day's adjustment. The program automatically keeps records for the amount of water that is not balanced, and makes adjustment in the future. For section one, there is not much direct diversions from water contractors, so the previous approach does not apply. So the approach used by CH2MHILL is adopted in

the tool. That is: for gains in section one an inflow is added at node 401. For losses in section one a diversion is added for O'Neill Forebay. It makes sense to treat section one specially because (1) it is relatively easier to assume water quality for the gains in section 1; (2) not much direct diversions from section one by contractors; (3) there are seven major pumping / generating flows in section 1, and the modification to either one will have effects on water bodies beyond section A.

### 3.4 Pre-process of water quality data

The tool was developed to process three types of water quality data, EC, Bromide and DOC. For water sources such as groundwater pump-in and storm water inflows, EC, Bromide and DOC values are assumed to be constant over time, but can vary from a location to another location. Thus the tool focuses more on processing water quality data for pumping at Banks and Jones Pumping plants. Historical EC and DOC data at Banks and Jones Pumping plants can be retrieved from CDEC using the tool for DSM2 Delta historical simulation. The tool for the Aqueduct model simply copies historical EC and DOC data at Banks and Jones Pumping Plants from the tool for Delta historical simulation. The tool also retrieves EC, DOC and finger printing output for Banks and Jones Pumping Plants from output DSS file created in Delta historical simulation.

The tool processes EC and DOC in a similar way. The tool uses historical EC and DOC data at Banks and Jones Pumping Plants as boundary inputs at these two locations for the Aqueduct model. In case EC/DOC data is missing for a period of time, the EC/DOC data estimated by Delta DSM2 model will be used to fill in missing data. The tool does not simply fill in missing data with data from DSM2 simulation, instead the differences among DSM2 estimated EC/DOC are used to fill in missing data. The detailed procedures are like this: (1) get DSM2 simulated EC/DOC for the period with observed missing EC/DOC data. If there exists observed EC/DOC data before the missing period, then also get calculated EC/DOC for the day just before the missing period; If there exists observed EC/DOC data after the missing period, then also get calculated EC/DOC for the day just after the missing period. The extended period is used to fill in missing data. (2) adjust the first and last EC/DOC data obtained in the first step so that the first and last EC/DOC data is the same as observed EC/DOC data at the same days. EC/DOC at other days should be modified accordingly. In rare case, there is no observed data after the data missing period, no extension is needed. So basically, the shape of the observed EC/DOC for the extended missing period is not changed, but it is rotated so its first and last data values are the same as observed EC/DOC data values.

For Bromide, the case is a little bit different. At present, the Delta DSM2 model does not calculate Bromide directly, so no DSM2 calculated Bromide can be used to fill in missing data. As an alternative, bromide data at Banks / Jones Pumping Plant is converted from DSM2 calculated EC and Martinez volumetric fingerprinting at Banks / Jones Pumping Plant according to the following expression:

$$Br = \min \left( 0.04, \begin{cases} 0.0004 * EC - 0.0364 & \text{if } vol_{mtz} < 0.4 \\ 0.000827 * EC - 0.1117 & \text{if } vol_{mtz} > 0.4 \end{cases} \right)$$

Where  $Vol_{mtz}$  is the volumetric contribution of water from Martinez, a downstream boundary for the DSM2 Delta Simulation Model.

The calculated bromide data is used to fill in missing bromide data. The steps are the same as for filling in missing EC and DOC data.

### **3.5 Exporting time-series data to DSS files**

Time-series data for DSM2 boundary condition are saved in the U.S. Army Corps of Engineers' Hydrologic Engineering Center Data Storage System, or HEC-DSS. HEC-DSS is a database system designed to efficiently store and retrieve scientific data that is typically sequential. Such data types include, but are not limited to, time series data, curve data, spatial-oriented gridded data, and others. The system was designed to make it easy for users and application programs to retrieve and store data.

After all hydraulic and water quality data has been pre-processed, they are put on several EXCEL worksheets in the format that can be directly exported to HEC-DSS files. To export data to or import data from a DSS file, the tool directly calls functions of HEC-DSS Excel Data Exchange Add-In, which is a Visual Basic Application for retrieving and storing both regular-interval time series and paired data directly from Excel to an HEC-DSS database file. Both HEC-DSS and the EXCEL Data Exchange Add-In can be downloaded from the U.S. Army Corps of Engineers' website.

(<http://www.hec.usace.army.mil/software/hecdss-dss.html>)

### **3.6 Execution of the DSM2 Aqueduct model**

The tool can be used to make changes to the configuration file used to run the DSM2 Aqueduct model. One can also run the DSM2 Aqueduct model from the tool. If the model is run through the tool, the tool will take control of the EXCEL file so the user cannot work on it. To avoid this problem, the user can run step 7 from the tool interface, kill the job when the DSM2 Aqueduct model begins to run, and then run the program from an independent DOS command window.

### **3.7 Post-processing of model results**

The tool does not do much in this step. A template EXCEL file has been created to plot time-series plots for EC, Bromide, and DOC at locations chosen by the Metropolitan Water District of Southern California. The chosen locations are: South Bay Pumping Plant, O'Neill Forebay Outlet to CA Aqueduct, Check 41, Silverwood Lake Inflow, Santa Clara Tank Inflow, CA Aqueduct Inflow to O'Neill Forebay, O'Neill P/G Plant, San Luis Reservoir, Check 21, Check 23 (Upstream of Semitropic Turn-ins), Check 25 (Downstream of Semitropic Turn-ins), Pool 28 (Tupman Rd Bridge Upstream of CVC), KWB and Arvin-Edison Turn-ins), Check 29, and Pyramid Lake Inflow. The tool will copy the specified template file to a working file folder, retrieve output from the output DSS file which is created after the DSM2 Aqueduct model is run, and put the retrieve data in the right EXCEL worksheets.

## 4. Model Verification

The original DSM2 Aqueduct model was calibrated using three-year data starting January 1, 2001. There was no verification based on independent data. The original model was calibrated to calculate water velocities, stages of water bodies, and EC. After the model was improved, the model was verified using 21-year data starting from January 1, 1990. Model verification includes comparisons between model predictions and known system data for not only flow, stage and salinity (EC), but also two other constituents, Bromide and DOC. The model was run using a warm-start file, which means that the initial conditions must be given for all DSM2 nodes. This is especially important for the San Luis Reservoir, since water residence time for San Luis Reservoir is much longer when compared with the California Aqueduct.

To estimate the predictive power of the model, the Nash–Sutcliffe (N-S) model efficiency coefficient is used. It is defined as:

$$E = 1 - \frac{\sum_{t=1}^T (Q_o^t - Q_m^t)^2}{\sum_{t=1}^T (Q_o^t - \overline{Q_o})^2}$$

where  $Q_o$  is observed values, and  $Q_m$  is modeled values.  $Q_o^t$  is observed value at time  $t$ .

Nash–Sutcliffe efficiencies can range from  $-\infty$  to 1. An efficiency of 1 ( $E = 1$ ) corresponds to a perfect match of modeled discharge to the observed data. An efficiency of 0 ( $E = 0$ ) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ( $E < 0$ ) occurs when the observed mean is a better predictor than the model. Essentially, the closer the model efficiency is to 1, the more accurate the model is.

### 4.1 Verification of Flow and Storage

The DSM2 Aqueduct model can produce flow rates and stages for reservoirs and each node of a channel. Since water balance was conducted for the main section of the California Aqueduct, and gains and losses were enforced to maintain water level of each pool, the verification was conducted only for flows in the Aqueduct and DMC. For the San Luis Reservoir, all inflows and outflows were specified, and no gains/losses were enforced, so the verification was conducted for stages.

Comparison of measured and observed flow are presented for Check 21, the Buena Vista Pumping Plant (Check 30 on the California Aqueduct), the Teerink Pumping Plant (Check 35 on the California Aqueduct), the Edmonston Pumping Plant (Check 40 on the California Aqueduct), and the Pearblossom Pumping Plant (Check 58 on the East Branch of the California Aqueduct). These locations are chosen because of the readily available flow data at the pumping plants.

The N-S efficiency for each location is listed in Table 4-1. The high N-S model efficiency for each location indicates that the model did pretty well in estimating flows at Checks 21, 30, 35, 40 and 58, and storage at San Luis Reservoir.

**Table 4-1.** Nash–Sutcliffe (N-S) model efficiency for check flows and reservoir storage

Location	SWP Check 21	SWP Check 30	SWP Check 35	SWP Check 40	SWP Check 58	San Luis Reservoir
variable	Flow	Flow	Flow	Flow	Flow	storage
N-S	0.94	0.82	0.81	0.78	0.86	0.85

Figures 4-1 to 4-5 present measured and modeled flow at Checks 21, 30, 35, 40 and 58. Figure 4.6 shows the comparison of measured and modeled storage of San Luis Reservoir. Figures 4-7 to 4-11 are the corresponding scatter plots with box charts for both measured and modeled flows. From those plots we can find that in general the model overestimated the flows at those checks. To examine the difference between measured and modeled flows at different flow ranges, we created exceedance curves (Figures 4-12 to 4-16) based on flow data for the period between 1990 and 2010. Overall as the exceedance percentage decreases, the difference between measured and modeled flows also increases. Shown on Figures 4-17 to 4-21 are box-whisker plots for measured and modeled flow. For a box-whisker plot, the bottom and top of the box are flows of the 25<sup>th</sup> and 75<sup>th</sup> percentile, the band near the middle of the box is the 50<sup>th</sup> percentile (median). The ends of the whiskers represent the lowest datum still within 1.5 interquartile range (IQR) of the lower quartile, and the highest datum still within 1.5 IQR of the upper quartile. From the box-whisker plots, we can find that for Checks 21 and 58, August is the month that modeled flows deviate the most from measured flows; For Checks 30, 35 and 40, modeled flows are more closer to measured flows for the period between October and December.

Water is pumped up-hill into the San Luis reservoir from the O'Neill Forebay when there exists surplus water, and is released back into the Forebay to continue downstream along the aqueduct as needed for farm irrigation and municipal uses. Considering the amount of water that is pumped into or released from San Luis reservoir, water quality in the reservoir is important for modeling water quality in the Aqueduct. The verification effort included comparing the model predictions with the reported storage in San Luis Reservoir. Figure 4-6 presents the measured and modeled storage at San Luis Reservoir. In DSM2, the reservoirs are represented as vertical walled vessels, and thus the storage is calculated using a constant surface area. In reality, San Luis Reservoir undergoes a considerable change in surface area throughout the year as the reservoir is drained in the summer months to provide water for deliveries downstream. Considering this limitation, the model provides a reasonable representation of the storage in the reservoir.

## 4.2 Verification of EC

As in the calibration period, salinity or EC was also investigated in the verification period. Comparison between modeled EC and measured EC is presented below for Aqueduct Checks 12, 13, 18, 21, 29, 41, 66, San Luis Reservoir, DMC Checks 13, 20 and 21, and South Bay Aqueduct Check 7. The source of measured EC data at SWP Checks 12, 13, 18, 21, 29, 41, 66, DMC Checks 13, 20 and 21, South Bay Aqueduct Check 7, and San Luis Reservoir was CDEC. Table 4-2 lists the N-S efficiency for each location. Except for DMC Checks 20, N-S efficiency for other locations is high enough to prove that model can calculate EC satisfactorily. The low N-S for DMC Check 20 was the result that the model did not do well for two periods. By getting rid of data during the two periods, the N-S coefficient will be increased to 0.53.

**Table 4-2.** Nash–Sutcliffe (N-S) model efficiency for EC calculation

Location	SWP CK 12	SWP CK 13	SWP CK 18	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 13	DMC CK 20	DMC CK 21	South Bay CK 7	San Luis Reservoir
N-S	0.81	0.89	0.93	0.92	0.56	0.49	0.70	0.88	0.14	0.38	0.87	0.67

Plots are presented in both time series format (Figures 4-22 to 4-33) and scatter format (Figures 4-34 to 4-45). Figures 4-22 to 4-25 show the modeled and measured EC at Aqueduct Checks 12, 13, 18 and 21 respectively. The modeled EC matches measured EC well at these four checks. The model did not predict several sudden decrease of EC at Check 12. It was noticed that the sudden decrease of measured EC is not observed at Check 13. So it is very possible that the measured EC at Check 12 at those times is not accurate. Figures 4-26 to 4-28 show the modeled and measured EC at Aqueduct Checks 29, 41, and 66 respectively. The modeled EC matches measured EC reasonably well at these three checks except for those periods with significant groundwater pump-in and storm water inflows.

Figures 4-29 to 4-31 show the modeled and measured EC at DMC Checks 13, 20 and 21 respectively. The modeled EC matches measured EC reasonably well at these three checks. For the period between January 2006 and August 2006, modeled EC does not match measured EC at DMC Checks 20 and 21. It is observed that during the same period modeled EC matches measured EC well at DMC Check 13, so the boundary EC data during this period is suspicious. Since measured EC at Checks 20 and 21 during this period is consistent, it seems that the measured EC during this period is reliable. Checking the hydrologic data collected by O&M finds no groundwater pump-ins and storm water inflows to the DMC during this period. The average difference between modeled EC and measured EC during this period is about 225 UMHOS/CM. To make the difference of 225 UMHOS/CM, a source of water with high EC value is needed. It is possible that some groundwater pump-ins to DMC near DMC check 20 was not recorded.

Figure 4-32 compares the model predicted EC in the San Luis Reservoir against the daily EC measured at the Pacheco Pumping Plant, which is located on the western (back) side of San Luis Reservoir. Data from the pumping plant is the only long-term data record available characterizing the EC in San Luis Reservoir. It must be understood that this gage is located in a shallower portion of the reservoir, away from the intake/outlet structure, and is thus not likely to be representative of average EC conditions in the entire reservoir. In general, the model reproduces the measured trend in EC in San Luis, but tends to underestimate the salinity for the second half of the simulation period. The model begins to deviate from the measured data in June 2002. But by the end of 2009, the modeled EC matches measured EC much better. It must be noted that DSM2 lacks the capability to remove water at a lower EC than its source. When water was removed from the San Luis Reservoir by evaporation, EC was also removed from the reservoir. So in the long term, evaporation tends to increase EC concentration, but this is not reflected in the model.

Figure 4-33 shows the comparison of the model predicted EC and measured EC at Check 7 of the South Bay Aqueduct. As expected, the modeled results match measured EC very well since pumping from Banks Pumping Plant is the only source of water for South Bay Aqueduct.

The plots in scatter format (Figures 4-34 to 4-45) show that the model does not have significant bias in estimating EC except for Aqueduct Check 66, DMC Checks 20 and 21, and the San Luis Reservoir. The model underestimated EC at those three locations. The exceedance curves for EC (Figures 4-46 to 4-57) are used to compare modeled and measured EC from another perspective. Figure 4-46 shows that when EC values are less than 600 UMHOS/CM, the exceedance curves for modeled and observed EC values at

SWP Check 12 are very close. This is expected since the main source of water at Check 12 is Banks Pumping Plant. For SWP Check 13 (Figure 4-47), EC is affected by flows from San Luis Reservoir, Delta Mendota Canal, and Banks Pumping Plant, the exceedance curves for modeled and observed EC show somewhat differences, especially for the EC range between 400 and 650 UMHOS/CM. After Check 13, water is more mixed, so the exceedance curves for modeled and observed EC at Checks 18, 21, and 29 (Figures 4-48 – 4-50) are much closer. For Checks 41 and 66 (Figures 51-52), the exceedance curve for simulated EC begins to diverge from the exceedance curve for observed EC when EC is greater than 550 UMHOS/CM. The difference between modeled and observed EC increases as EC increases. The reason is that the model failed to reproduce several EC peaks that may be caused by groundwater pump-in. More groundwater pump-in data in the future may help solve the problem. The exceedance curve for simulated EC at Check 7 of South Bay Aqueduct and DMC Check 13 matches very well with the exceedance curve for measured EC (Figures 53-54). For DMC Checks 20 and 21 (Figures 55-56), the simulated EC values are lower than the observed EC values for the same exceedance percentage. The difference between modeled EC and observed EC increases when EC decreases. The model did not predict some high EC values with less than 5% exceedance. For San Luis Reservoir, the simulated EC values are lower than the observed EC values for the same exceedance percentage that is above 20%. The simulated EC values are generally greater than the observed EC values for exceedance percentage below 20%, except for exceedance percentage below 5%.

The Box-Whisker plots in Figures 4-58 to 4-69 show the comparison of the lower quartile (Q1), median (Q2), upper quartile (Q3) of modeled and observed EC. Overall, the monthly medians of modeled and observed EC at each location are close. However, monthly ranges of box and whisker can sometimes be quite different. For SWP Check 12, the monthly mean of modeled EC is equal or greater than that of observed EC except for June. For San Luis Reservoir, the monthly mean of modeled EC is equal or less than that of observed EC.

### 4.3 Verification of Bromide

In the calibration period, only salinity or EC was investigated. In the verification period, besides EC, Bromide was also investigated. The model setup for Bromide simulation was exactly the same for EC simulation. The only difference was that the boundary conditions for Bromide simulation were changed. Measured Bromide data is available for Aqueduct Checks 13, 21, 29, 41, 66, DMC Check 12, South Bay Aqueduct Check 7, and San Luis Reservoir. Measured Bromide data is scarce for those locations except for SWP Checks 13, 41 and 66. The sources for measured Bromide include, WDL and MWD. Table 4-3 summarizes the data sources for each location. For SWP Check 66, the Bromide data at Silverwood Lake from WDL besides data provided by MWD was used for comparison. For San Luis Reservoir, the Bromide data at the Pacheco Pumping Plant (PPP) was the only source available for the verification period (1990-2010). No grab sampled Bromide data at DMC Check 12 (milepost 63.99) was available, instead grab sampled data at mile post 67.15 and 68.03 was chosen. Table 4-4 lists the N-S efficiency for each location. Overall the model did a pretty well job in estimating Bromide at all locations.

**Table 4-3.** Bromide data source for each location

Location	SWP CK 13	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 12	South Bay CK 7	San Luis Reservoir
sources	CDEC, WDL, WMD	WDL	CDEC, WDL	CDEC, WDL, WMD	WDL <sup>1</sup> , MWD	WDL <sup>2</sup>	WDL	WDL <sup>3</sup> , CDEC <sup>4</sup>

\*(1) Silverwood Lake (2) Mile post 67.15 and milepost 68.03 (3) Pacheco Pumping Plant (4) Pacheco Pumping Plant

**Table 4-4.** Nash–Sutcliffe (N-S) model efficiency for Bromide calculation

Location	SWP CK 13	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 12	South Bay CK 7	San Luis Reservoir
N-S	0.85	0.79	0.46	0.61	0.78	0.60	0.95	0.83

Plots are presented in both time series format (Figures 4-70 to 4-77) and scatter format (Figures 4-78 to 4-85). No obvious bias is observed for Bromide simulation from those plots. Even though measured data is scarce for most locations, the available data covers periods long enough to include different hydrologic conditions and a wide range of data values. For most locations, the values of Bromide can vary from 0.1 to 0.45 mg/l from time to time except San Luis Reservoir, which has a much narrow range of variation between 0.15 and 0.30 mg/l. Only during a period between August 2008 and August 2009 the values of Bromide exceed 0.30 mg/l.

Figures 4-86 to 4-93 show exceedance curves for Bromide at the previous stated locations. Figure 4-86 shows that modeled and observed Bromide at SWP Check 13 are close, especially when Bromide concentration is less than 0.30 mg/l, which is around 22% exceedance level. A similar exceedance curve exists for SWP Check 21 (Figure 4-87). When Bromide concentration is less than 0.25 mg/l, which is around 35% exceedance level, the model did better job. For SWP Check 29 (Figure 4-88), exceedance curves for modeled and measured Bromide are close, especially Bromide concentration is less than 0.30 mg/l, which is around 15% exceedance level. For SWP Check 41 (Figure 4-89), the model did a better job when Bromide concentration is greater than 0.20 mg/l, which is around the 45% exceedance level. Surprisingly, the exceedance curves of the modeled and observed Bromide at SWP Check 66 (Figure 4-90), are close, especially when Bromide concentration is low. It is no surprise that the exceedance curves of the modeled and observed Bromide at South Bay Aqueduct Check 7 (Figure 4-91), are very close since the water quality in the South Bay Aqueduct is mainly affected by one of the boundaries, Banks Pumping Plant. For DMC Check 12, the exceedance curves of the modeled and observed Bromide are close (Figure 4-92). The model tended to overestimate Bromide when Bromide concentration is less than 0.2 mg/l, and overestimate Bromide when concentration is greater than 0.2 mg/l. The exceedance curves of the modeled and observed Bromide for San Luis Reservoir are close (Figure 4-93).

The Box-Whisker plots in Figures 4-94 to 4-101 show the comparison of the lower quartile (Q1), median (Q2), upper quartile (Q3) of modeled and observed Bromide. Overall, the monthly median values of modeled and observed bromide at each location are close. However, monthly ranges of box and whisker can sometimes be quite different. The differences between monthly median values of modeled and measured Bromide can be positive or negative for each location. No trend is observed.

#### 4.4 Verification of DOC

In the verification period, the DOC simulation was also investigated. The model setup for DOC simulation was exactly the same for EC and Bromide simulation. The difference was that the boundary conditions for DOC simulation were changed. Measured DOC data is available for Aqueduct Checks 12, 13, 21, 29, 41, 66, DMC Check 12, South Bay Aqueduct Check 7, and San Luis Reservoir. Measured DOC data is scarce for those locations except for SWP Checks 13, 41 and 66. The sources for measured

Bromide include CDEC, WDL and MWD. Table 4-5 summarizes the data sources for each location. For San Luis Reservoir, the DOC data at the Pacheco Pumping Plant (PPP) was the only source available for the verification period (1990-2010). Limited grab sampled Bromide data at DMC Check 12 was available, grab sampled data at mile post 67.15 and 68.03 was chosen for comparison. Table 4-6 lists the N-S efficiency for each location. Overall the model did a reasonably well job in calculating DOC, but not as well as calculating EC and Bromide. The reason may be that DOC is more subjected to decay during the traveling process.

**Table 4-5.** Bromide data source for each location

Location	SWP CK 12	SWP CK 13	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 12	South Bay CK 7	San Luis Reservoir
sources	WDL	CDEC, WDL, WMD	WDL	WDL	WDL, WMD	WDL MWD	WDL <sup>1</sup>	WDL	WDL <sup>2</sup> CDEC <sup>3</sup>

\*(1) Check 12, mile post 67.15 and milepost 68.03 (2) Pacheco Pumping Plant (3)Pacheco Pumping Plant

**Table 4-6.** Nash–Sutcliffe (N-S) model efficiency for DOC calculation

Location	SWP CK 12	SWP CK 13	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 12	South Bay CK 7	San Luis Reservoir
N-S	0.20	0.79	0.81	0.64	0.56	0.43	0.34	0.61	0.25

Plots are presented in both time series format (Figures 4-102 to 4-110) and scatter format (Figures 4-111 to 4-119). No obvious bias is observed in DOC simulation for all locations except for SWP Checks 41 and 66, DMC Check 12, and San Luis Reservoir. The model underestimated DOC at SWP Checks 41 and 66, and DMC Check 12 a little bit, but overestimated DOC at San Luis Reservoir a little bit for a period between 2005 and 2007. The model treated DOC as a conservative constituent so the underestimation of DOC at SWP Checks 41 and 66 was not related to DOC decay.

Figures 4-120 to 4.128 show exceedance curves for DOC at the previous stated locations. Figure 4-120 shows that model underestimated DOC at SWP Check 12 when DOC is less than 3.0 mg/l, but overestimated DOC when DOC is greater than 3.0 mg/l. Figure 4-120 shows that modeled and observed DOC at SWP Check 13 are close, especially when DOC concentration is less than 4.5 mg/l and greater than 2.2 mg/l. The modeled DOC exceedance curve matches the measured DOC exceedance curve very well for SWP Check 21(Figure 4-122). For SWP Check 29(Figure 4-123), exceedance curves for modeled and measured Bromide are close, especially DOC concentration is greater than 2.2 mg/l, which is around 80% exceedance level. For SWP Check 41(Figure 4-124), the model underestimated DOC for almost all exceedance level except for level greater than 95%. For SWP Check 66(Figure 4-125), the model underestimated DOC for all exceedance level. It is no surprise that the exceedance curves of the modeled and observed DOC at South Bay Aqueduct Check 7 (Figure 4-126) match well since the water quality in the South Bay Aqueduct is mainly affected by one of the boundaries, Banks Pumping Plant. For DMC Check 12 (Figure 4-127), the model underestimated DOC for all exceedance level. The possible reason may be that agricultural drainage to the Aqueduct was not accounted for. For San Luis Reservoir, the model overestimated DOC for almost all exceedance level (Figure 4-128).

The Box-Whisker plots in Figures 4-129 to 4-137 show the comparison of the lower quartile (Q1), median (Q2), upper quartile (Q3) of modeled and observed DOC. For SWP Checks 12, 13, 21, and 29, DMC Check 12, South Bay Aqueduct Check 7, the differences between monthly median values of modeled and measured DOC can be positive or negative for each location. No trend is observed. For SWP Checks 41 and 66, all monthly median values of modeled DOC are less than the corresponding median values of measured DOC. For San Luis Reservoir, all monthly median values of modeled DOC are greater than the corresponding median values of measured DOC.

Figure 4.1 Comparison of Measured and Simulated Flow at California Aqueduct Check 21

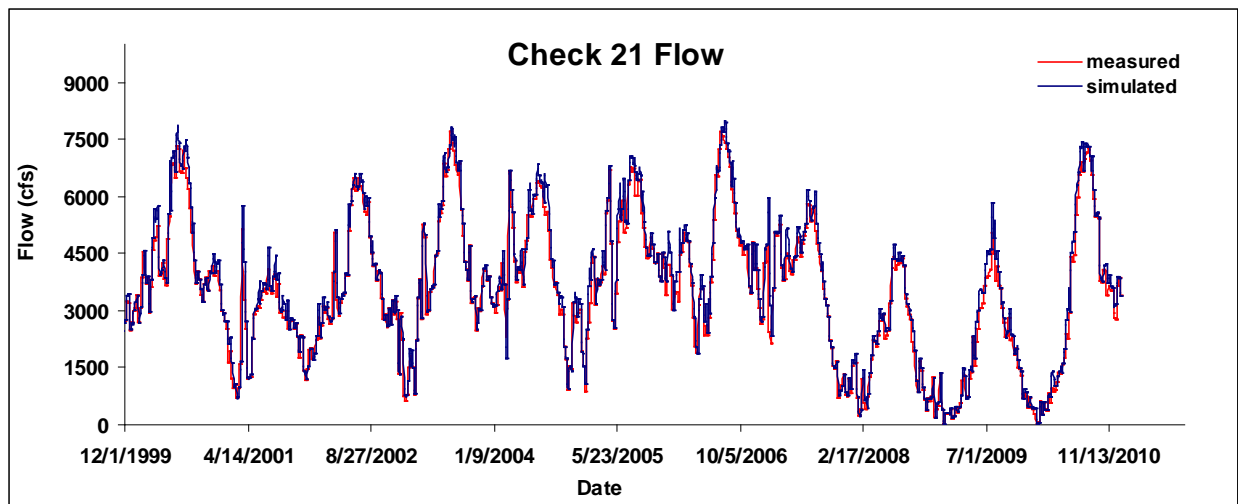
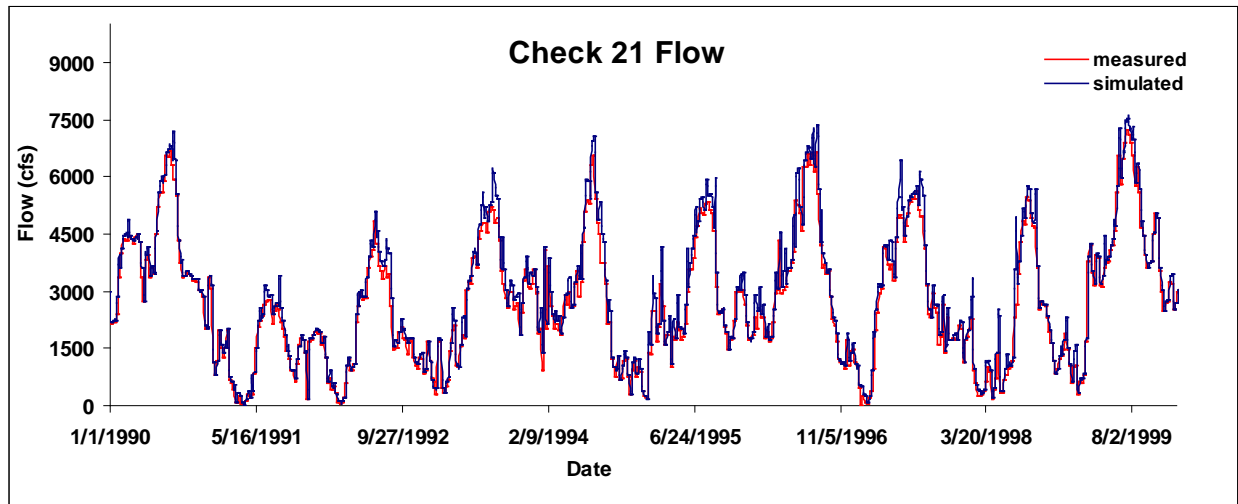


Figure 4.2 Comparison of Measured and Simulated Flow at California Aqueduct Check 30

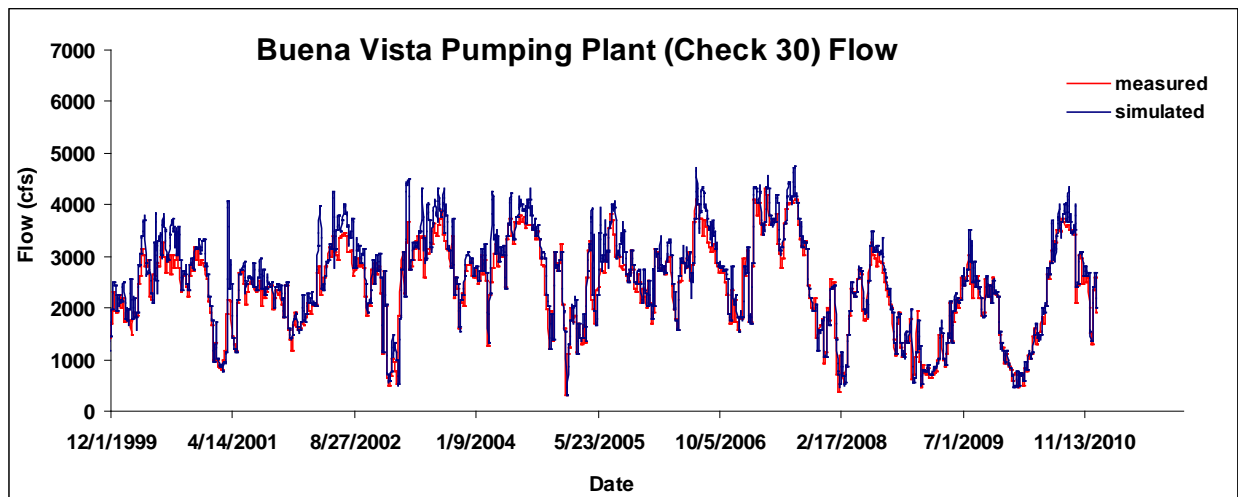
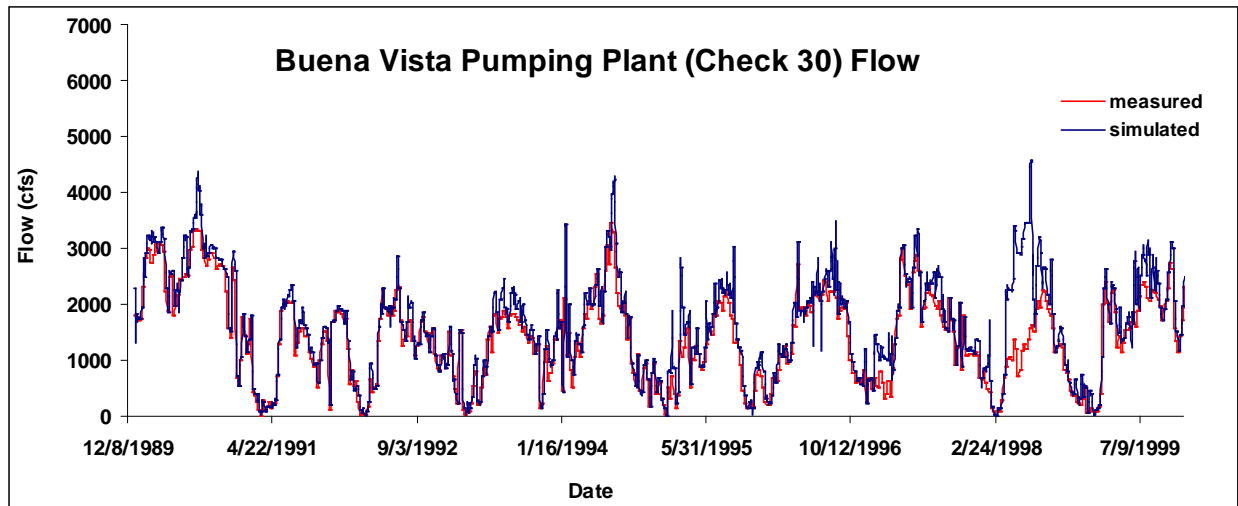


Figure 4.3 Comparison of Measured and Simulated Flow at California Aqueduct Check 35

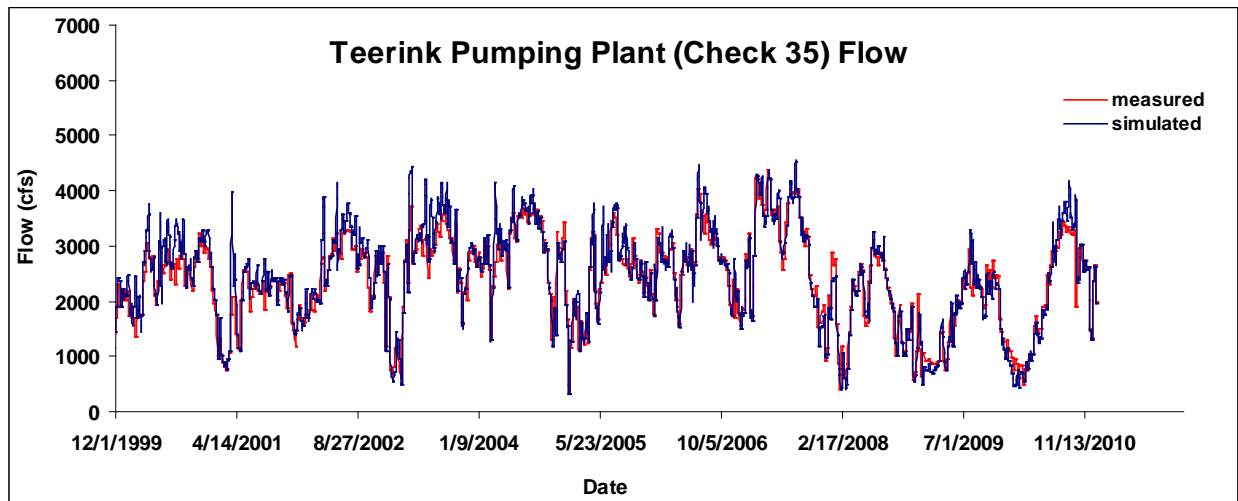
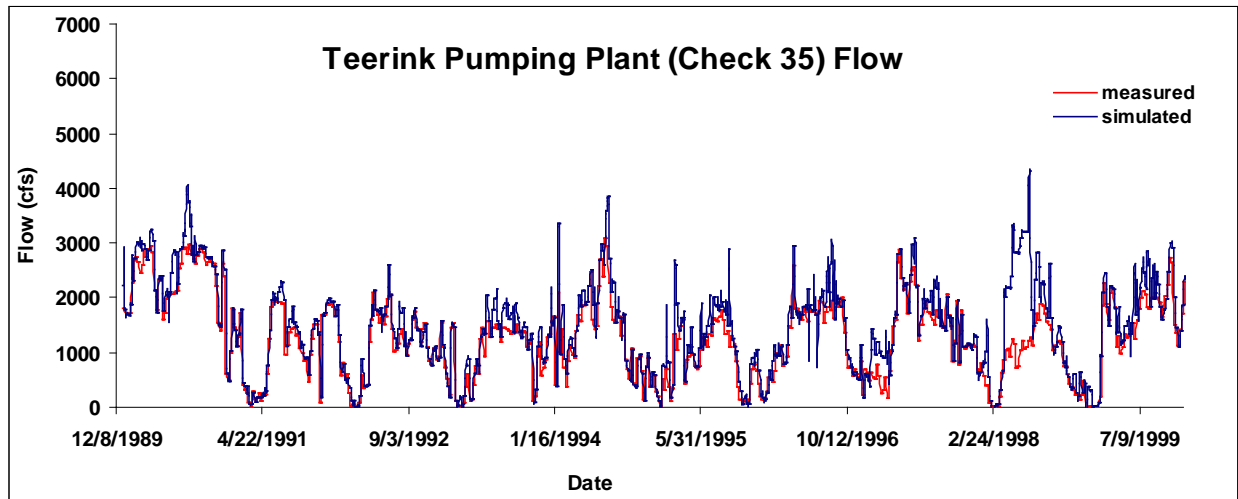


Figure 4.4 Comparison of Measured and Simulated Flow at California Aqueduct Check 40

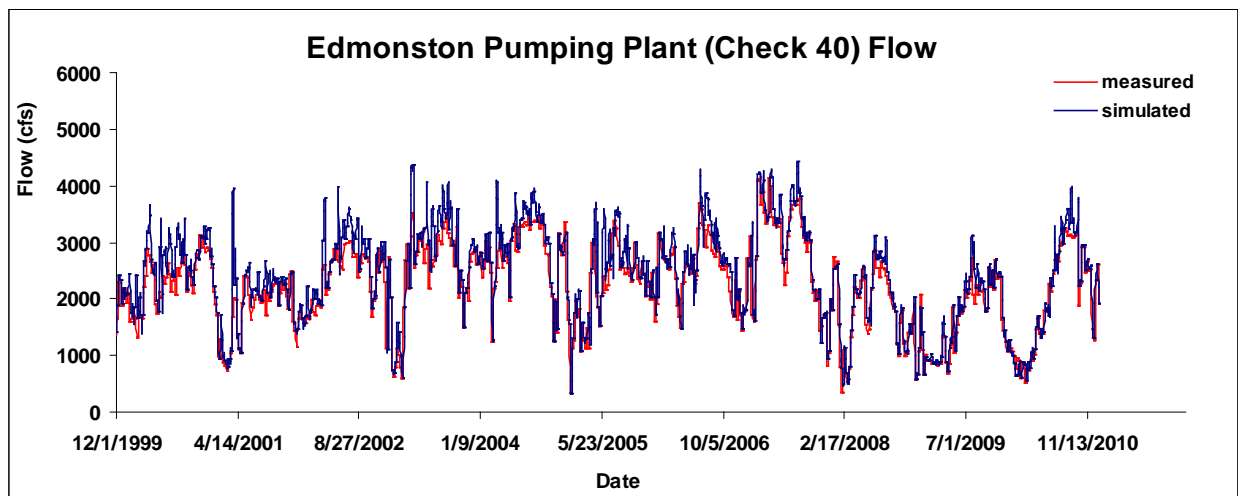
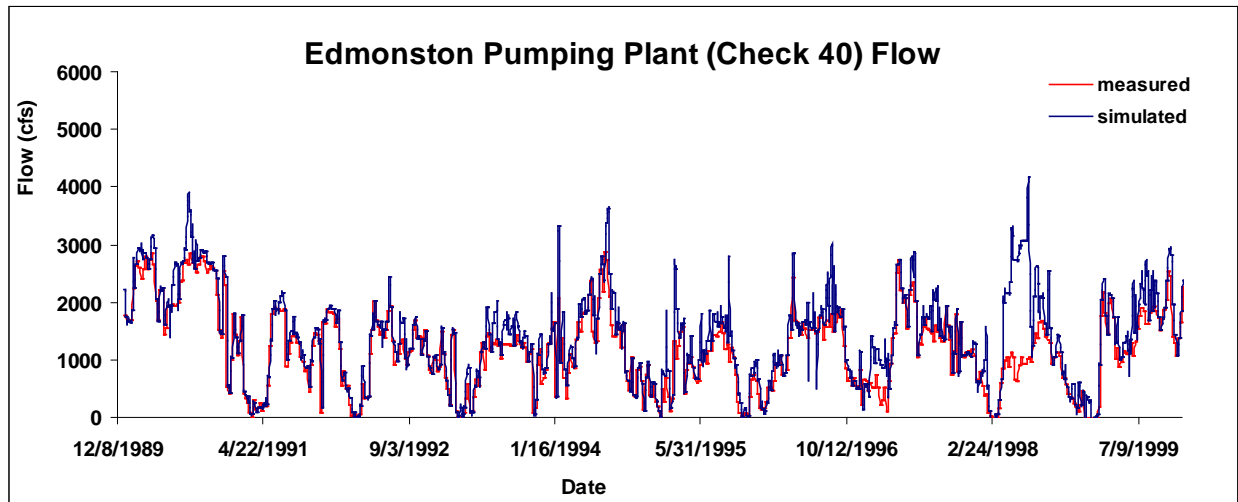


Figure 4.5 Comparison of Measured and Simulated Flow at California Aqueduct Check 58

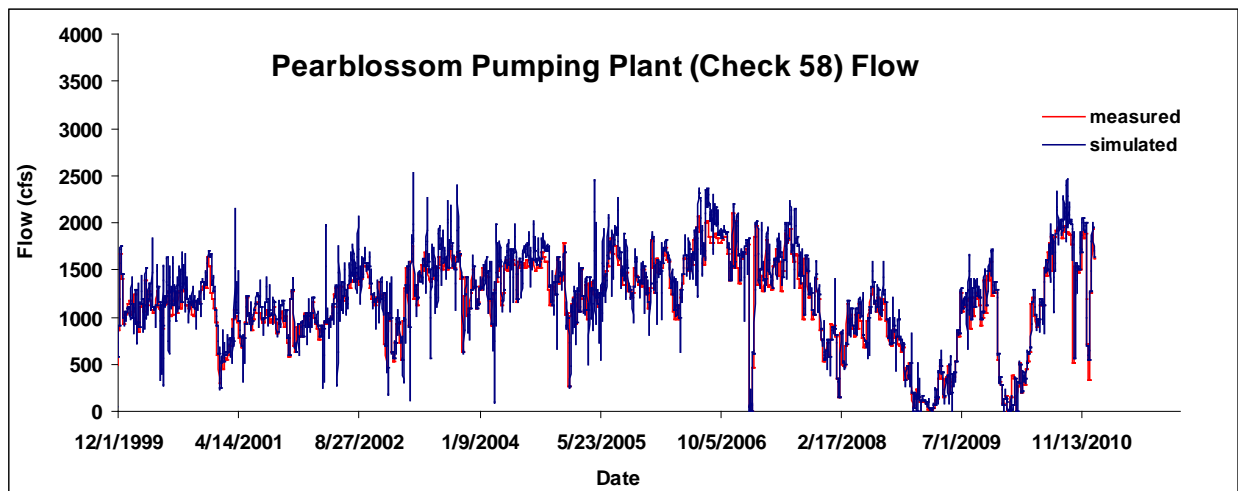
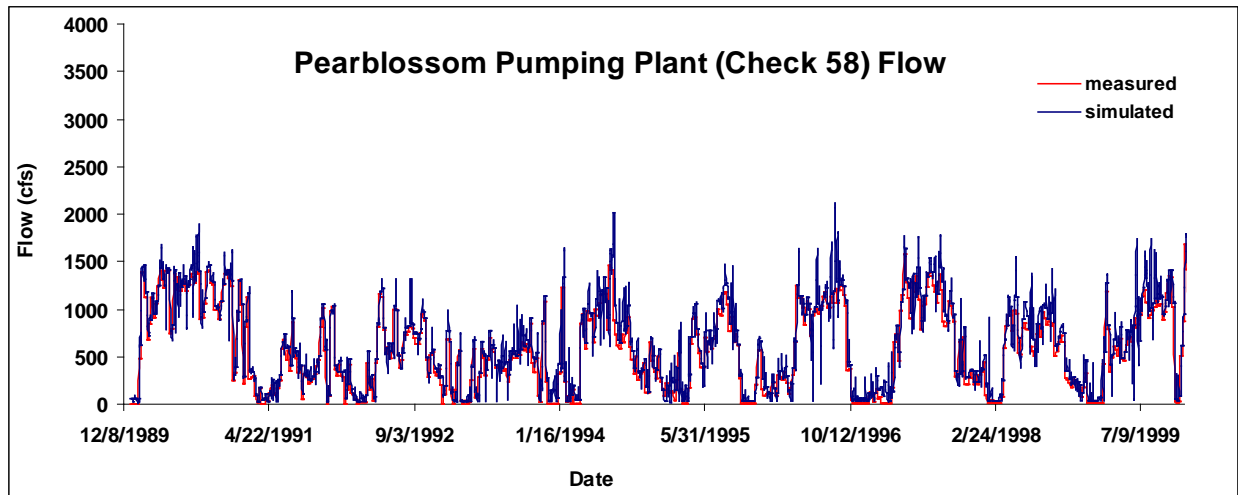


Figure 4.6 Comparison of Measured and Simulated Storage of San Luis Reservoir

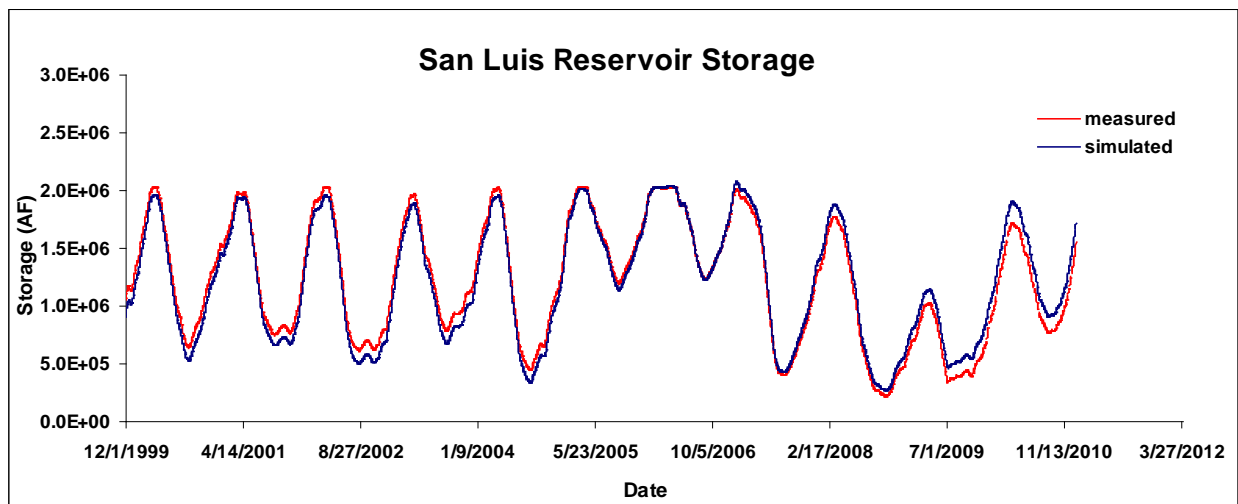
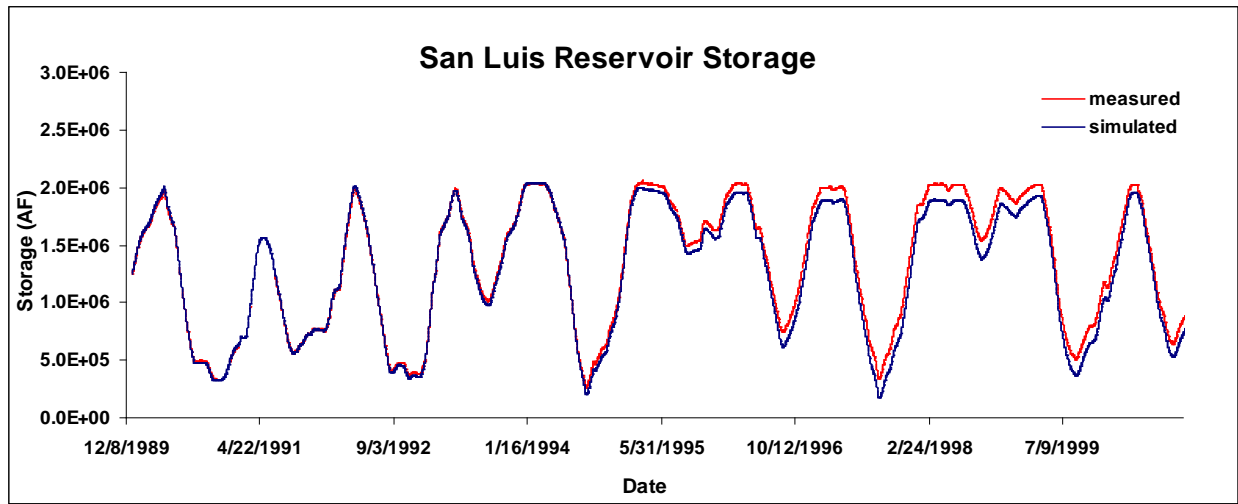


Figure 4.7 Scatter Plot for Flow at California Aqueduct Check 21

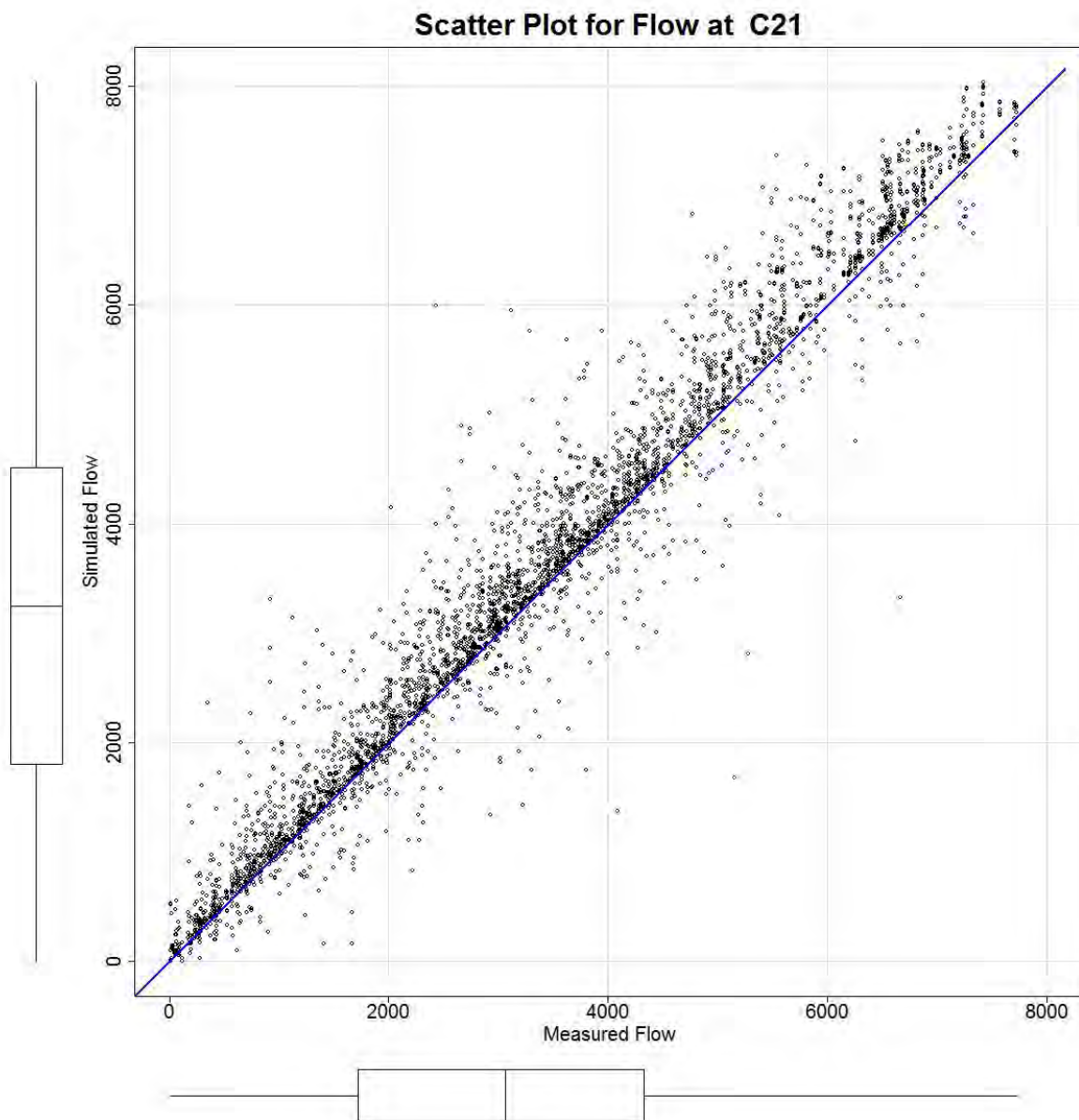


Figure 4.8 Scatter Plot for Flow at California Aqueduct Check 30

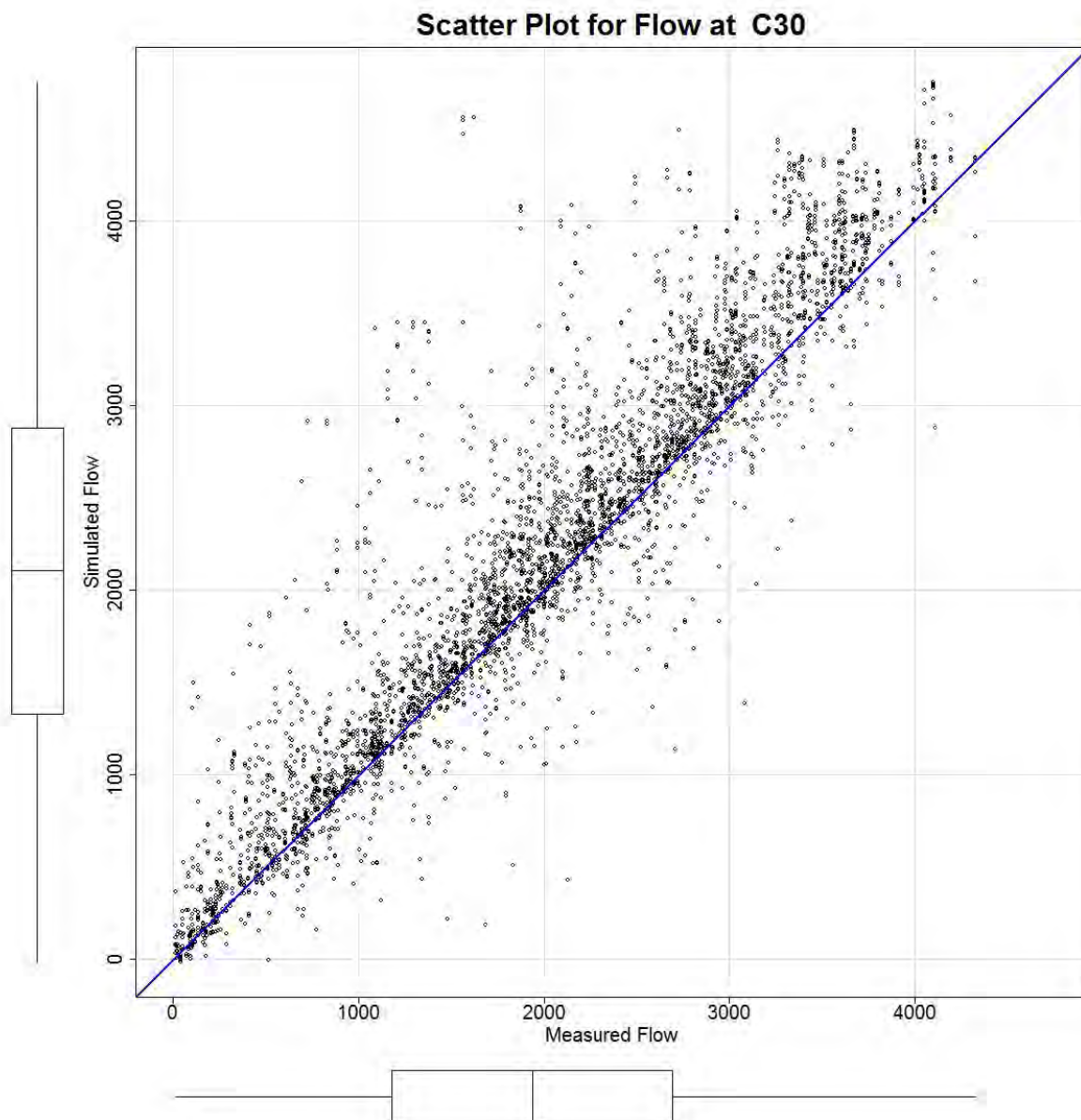


Figure 4.9 Scatter Plot for Flow at California Aqueduct Check 35

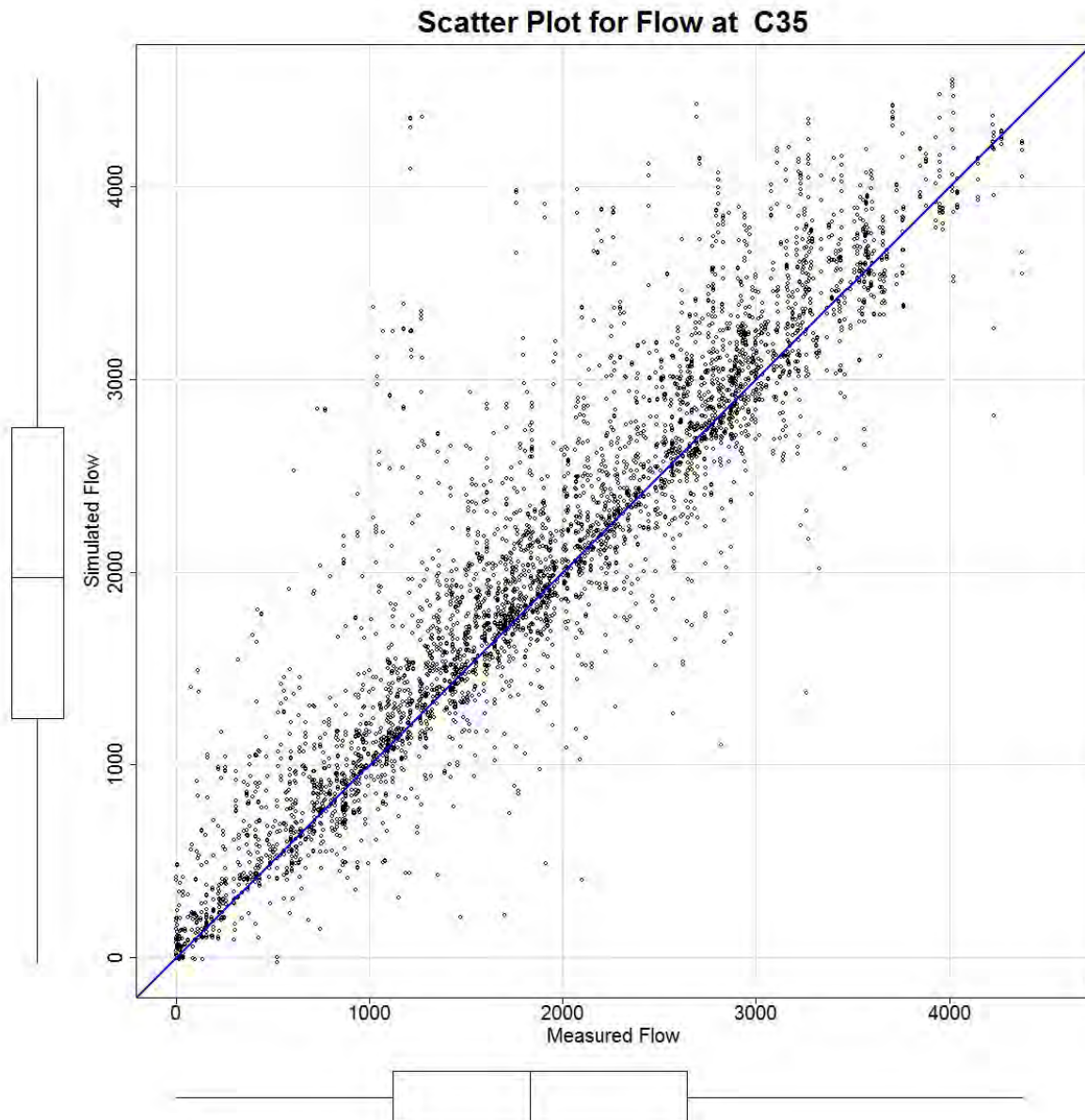


Figure 4.10 Scatter Plot for Flow at California Aqueduct Check 40

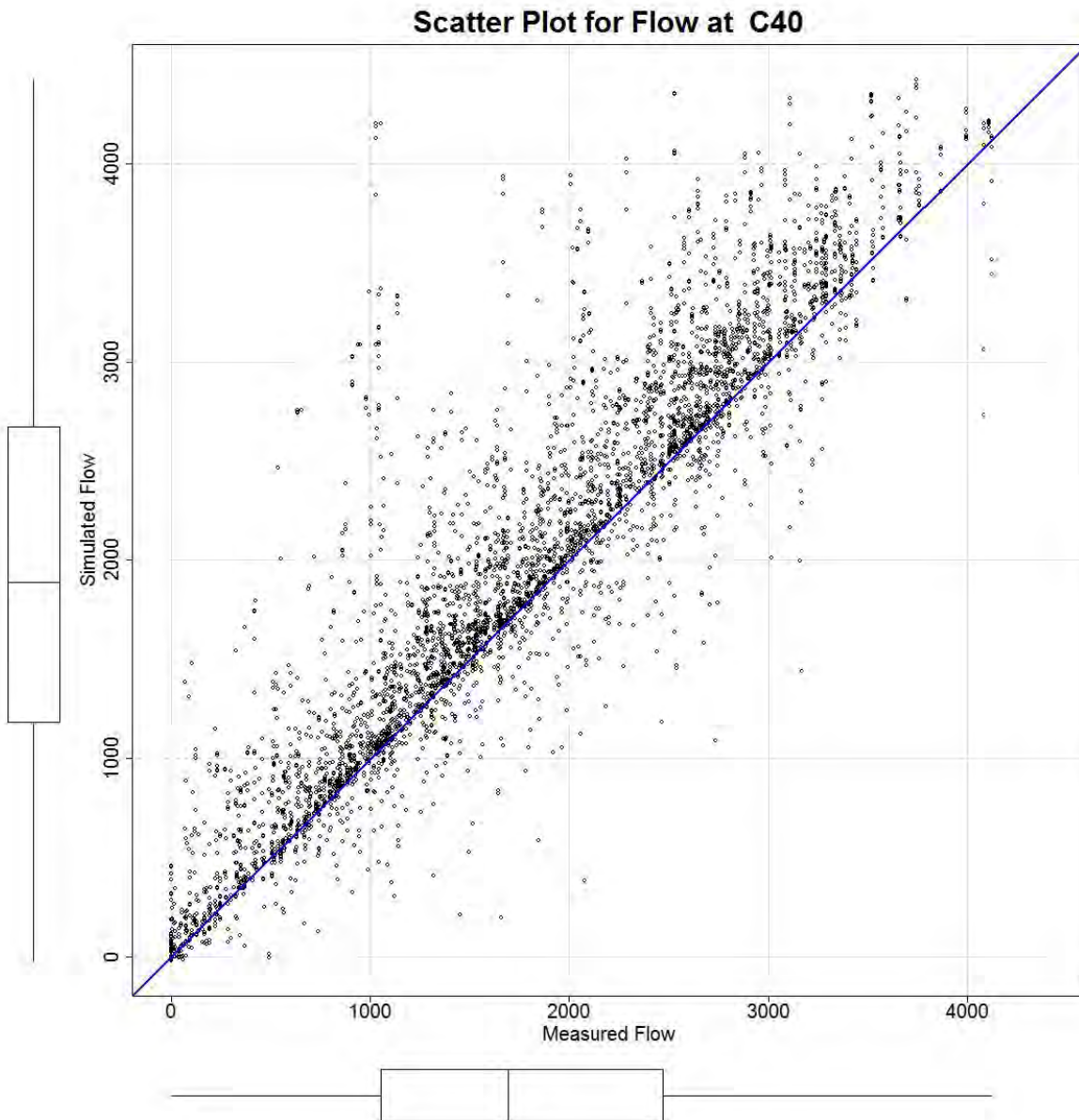


Figure 4.11 Scatter Plot for Flow at California Aqueduct Check 58

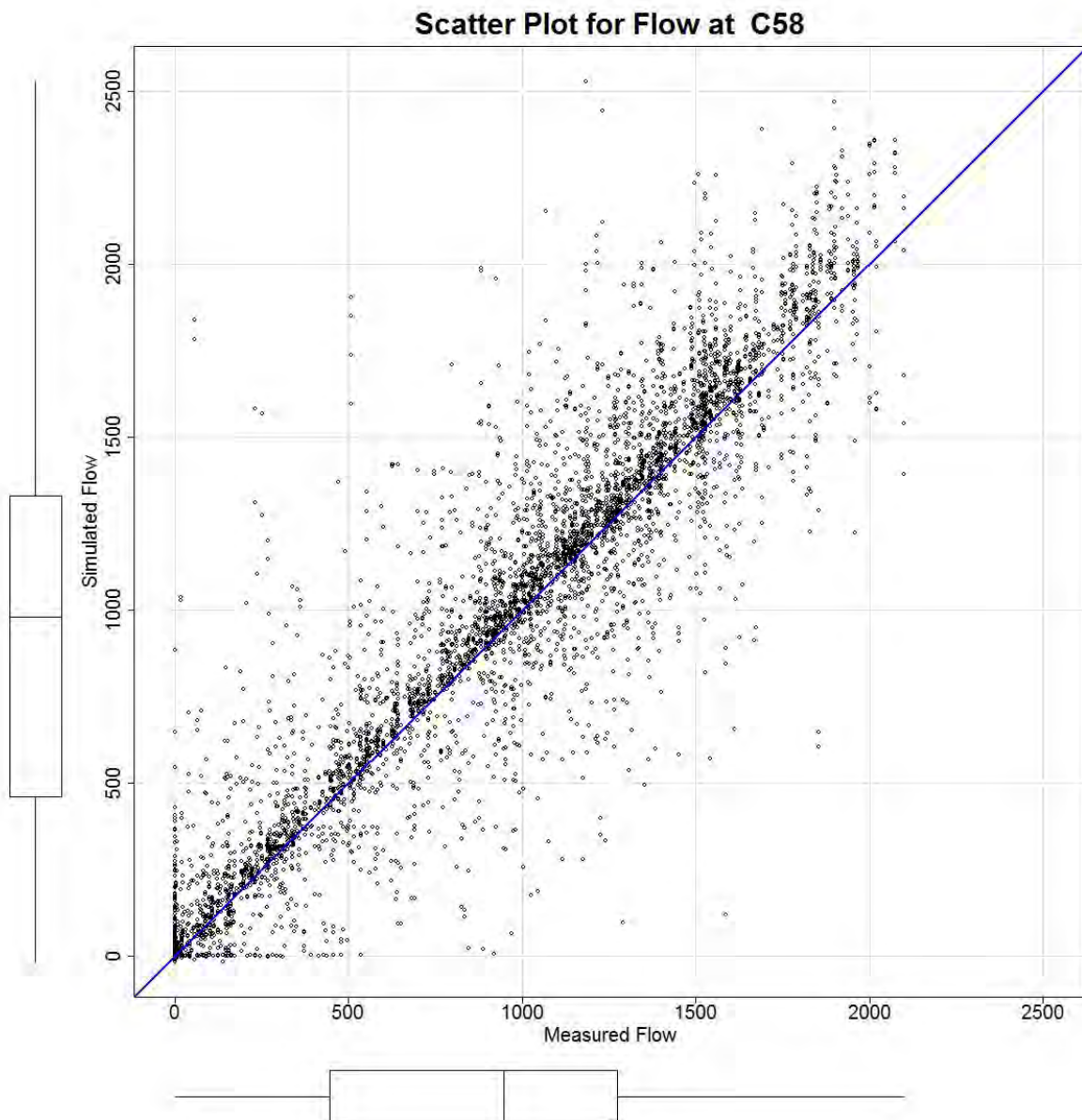


Figure 4.12 Exceedance Curve for Flow at California Aqueduct Check 21

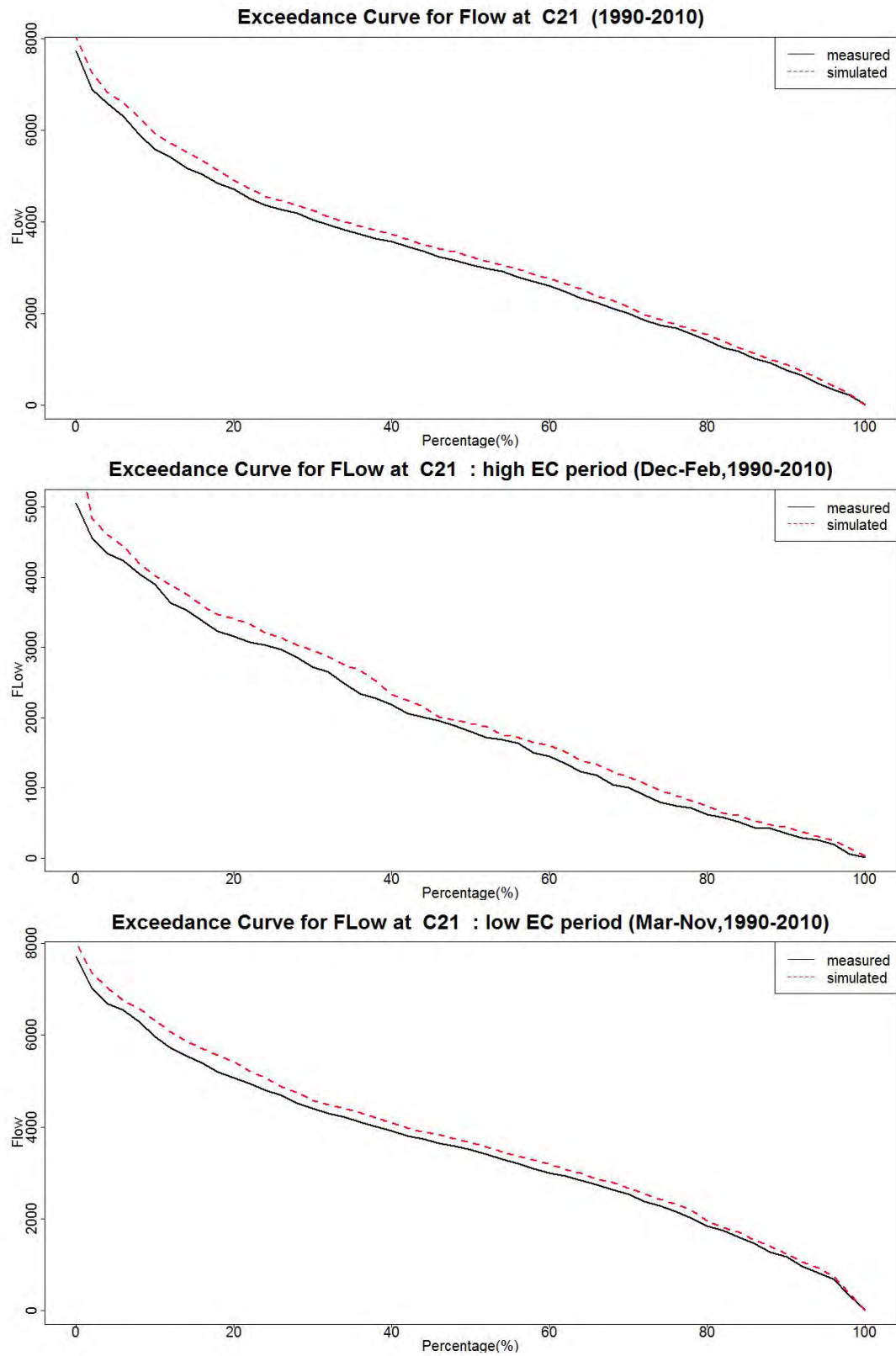


Figure 4.13 Exceedance Curve for Flow at California Aqueduct Check 30

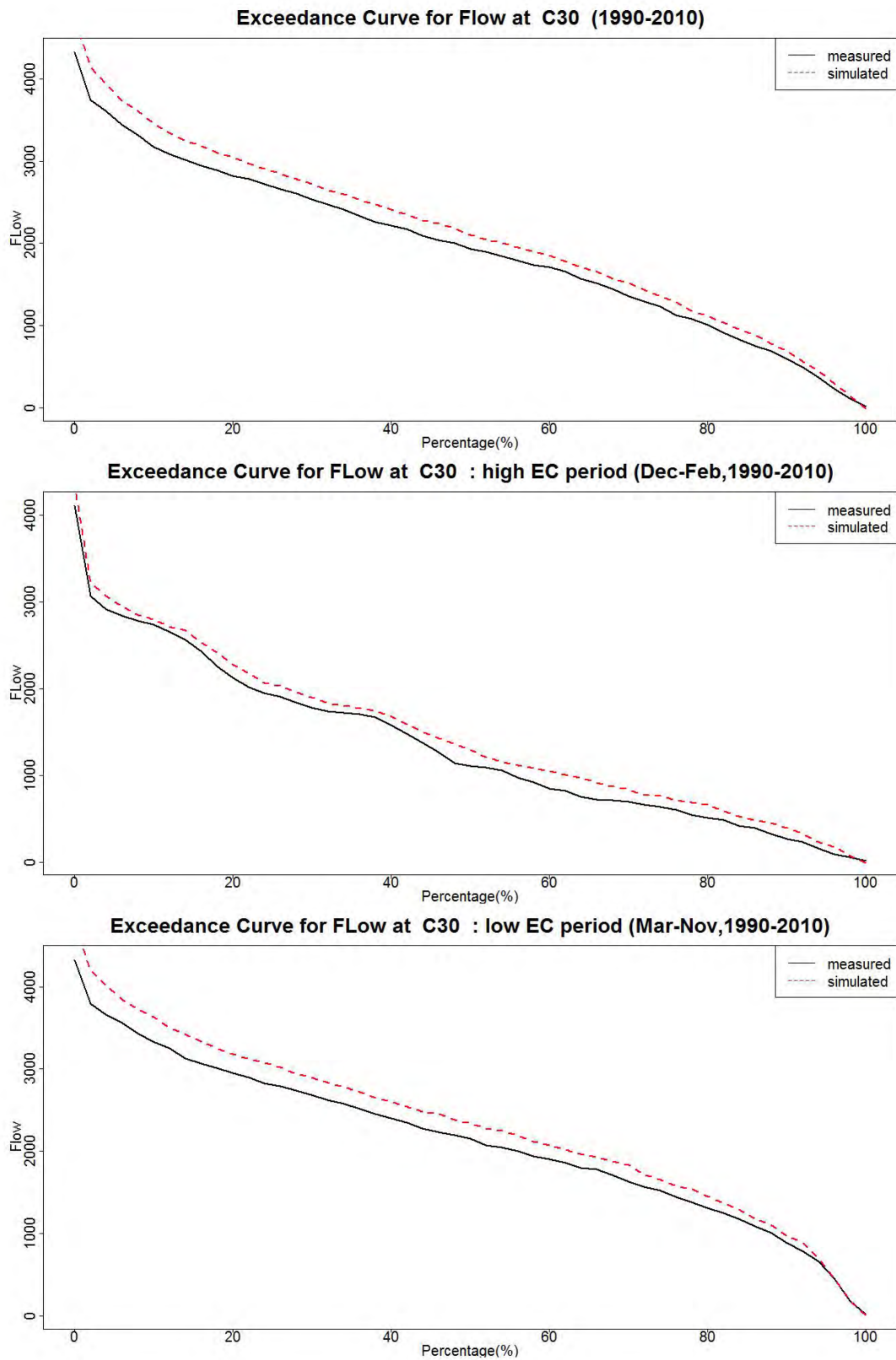


Figure 4.14 Exceedance Curve for Flow at California Aqueduct Check 35

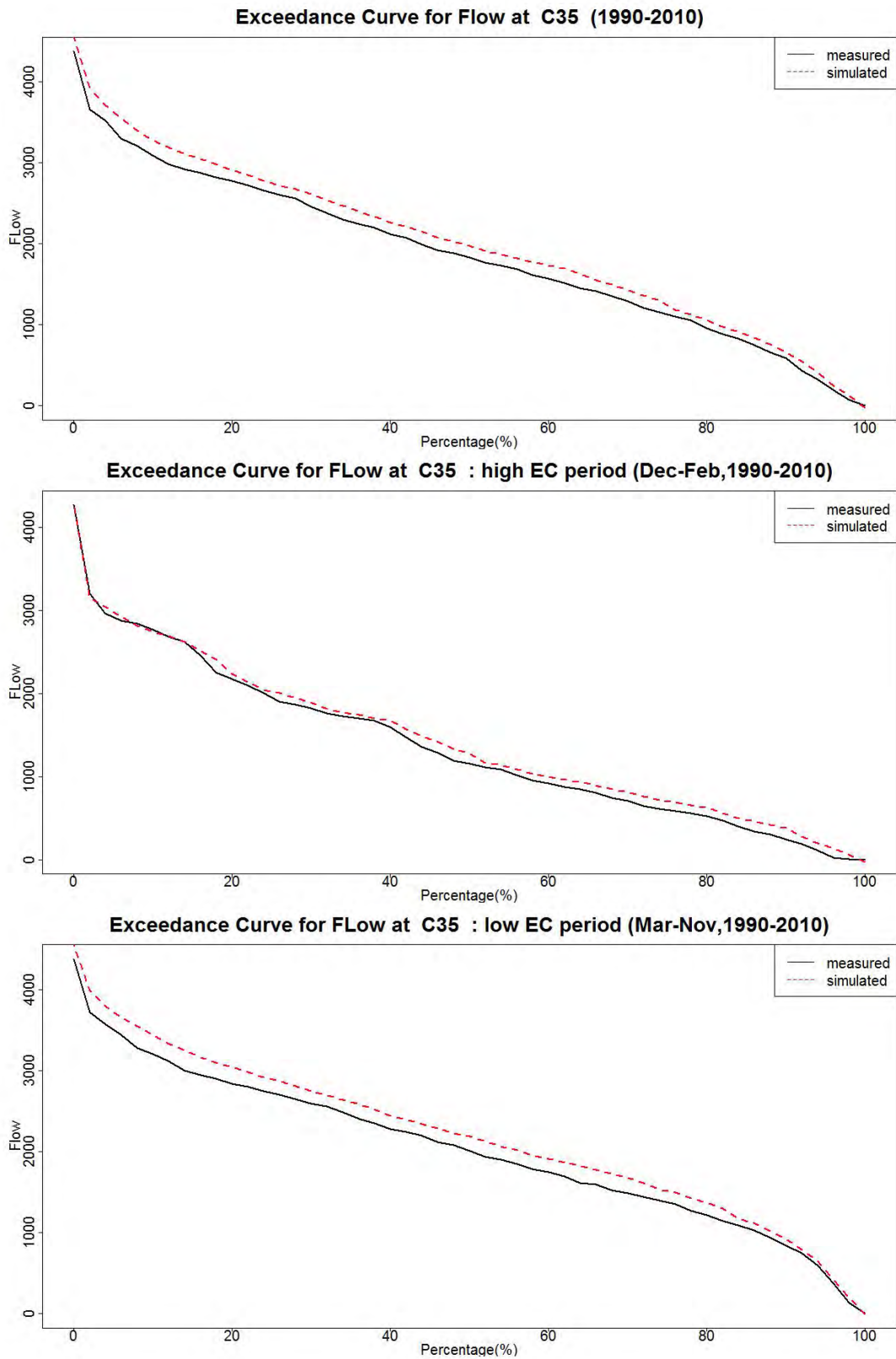


Figure 4.15 Exceedance Curve for Flow at California Aqueduct Check 40

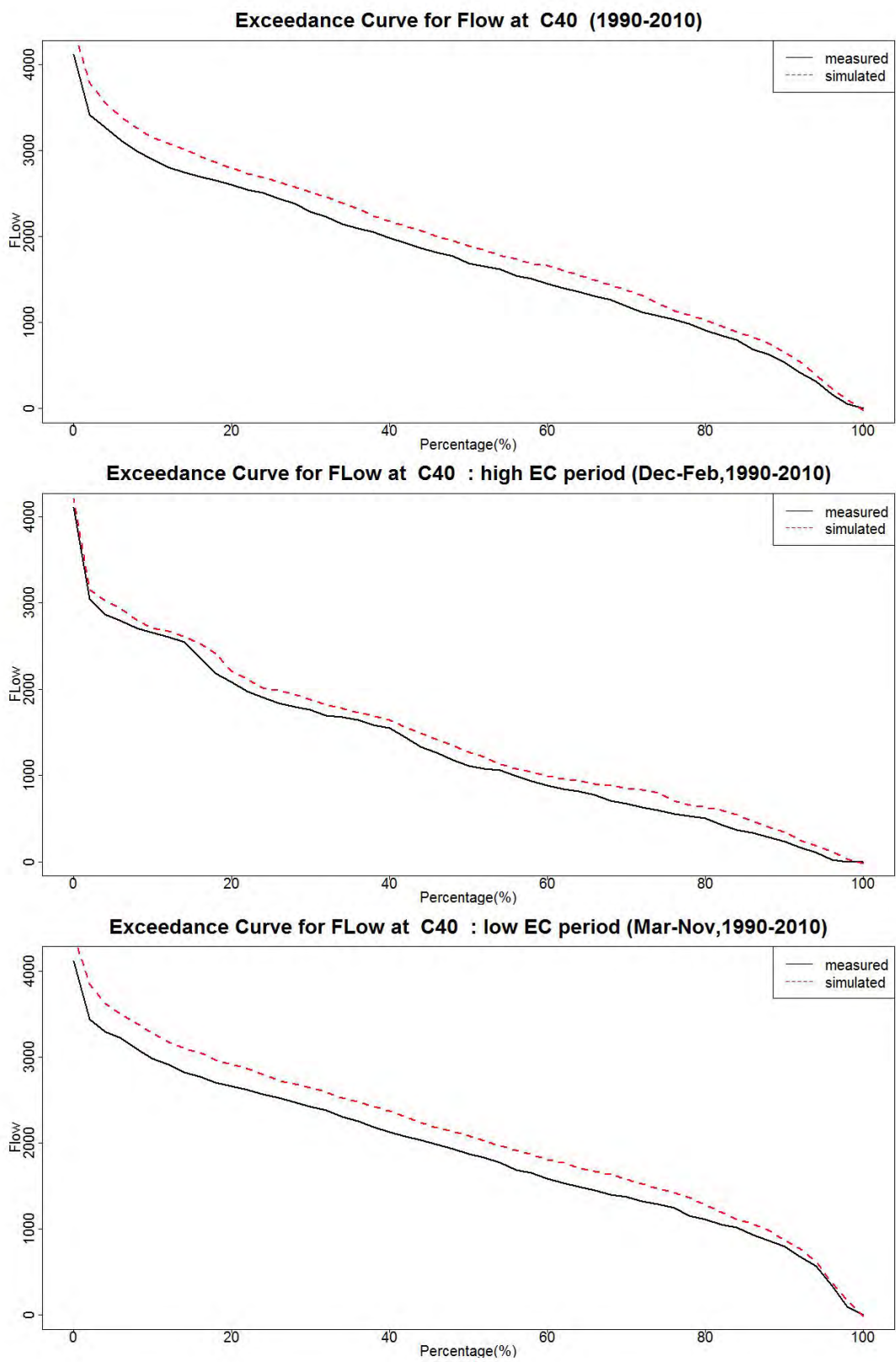


Figure 4.16 Exceedance Curve for Flow at California Aqueduct Check 58

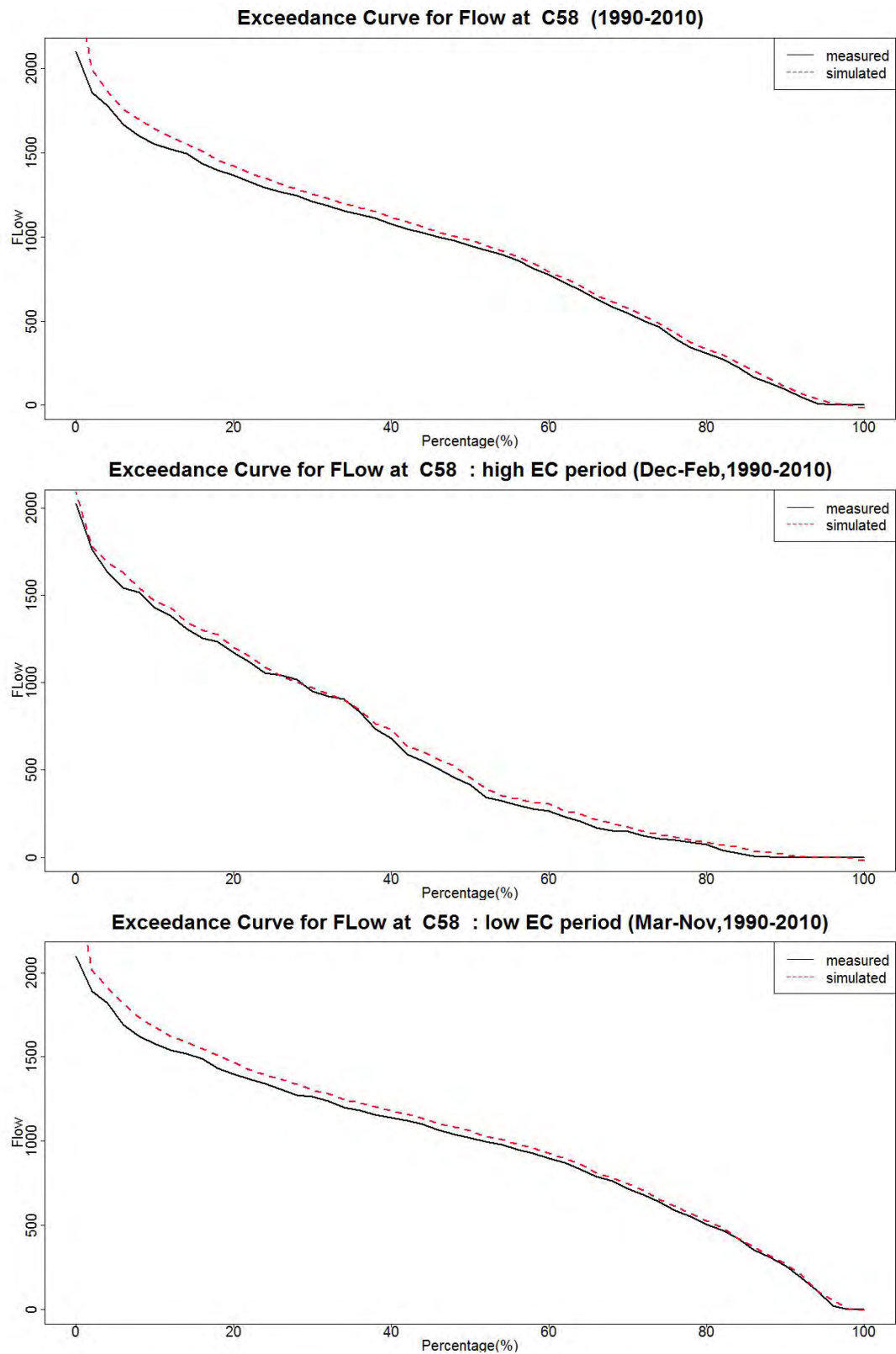


Figure 4.17 Month by Month Comparison of Measured and Simulated Flow at California Aqueduct Check 21

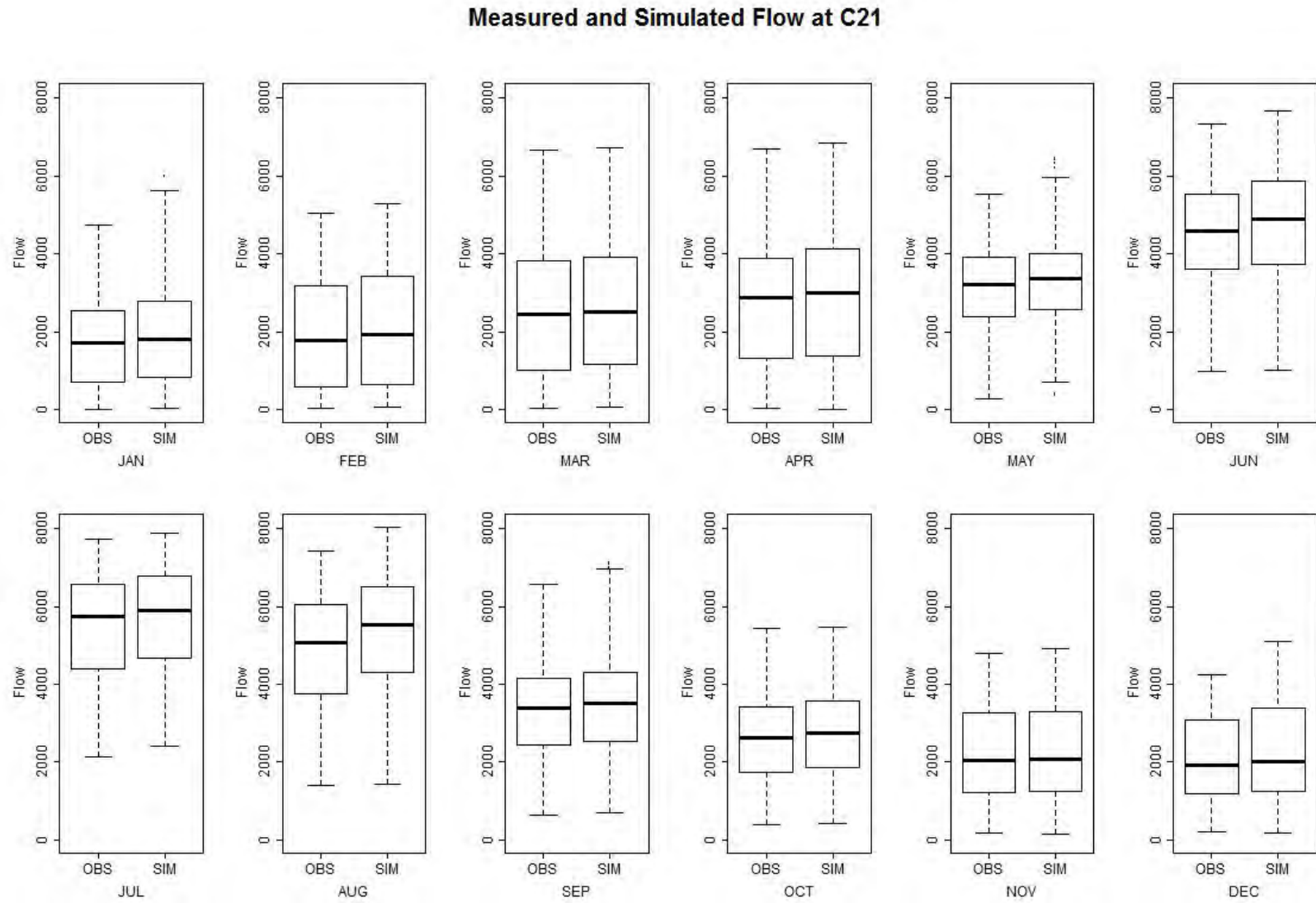


Figure 4.18 Month by Month Comparison of Measured and Simulated Flow at California Aqueduct Check 30

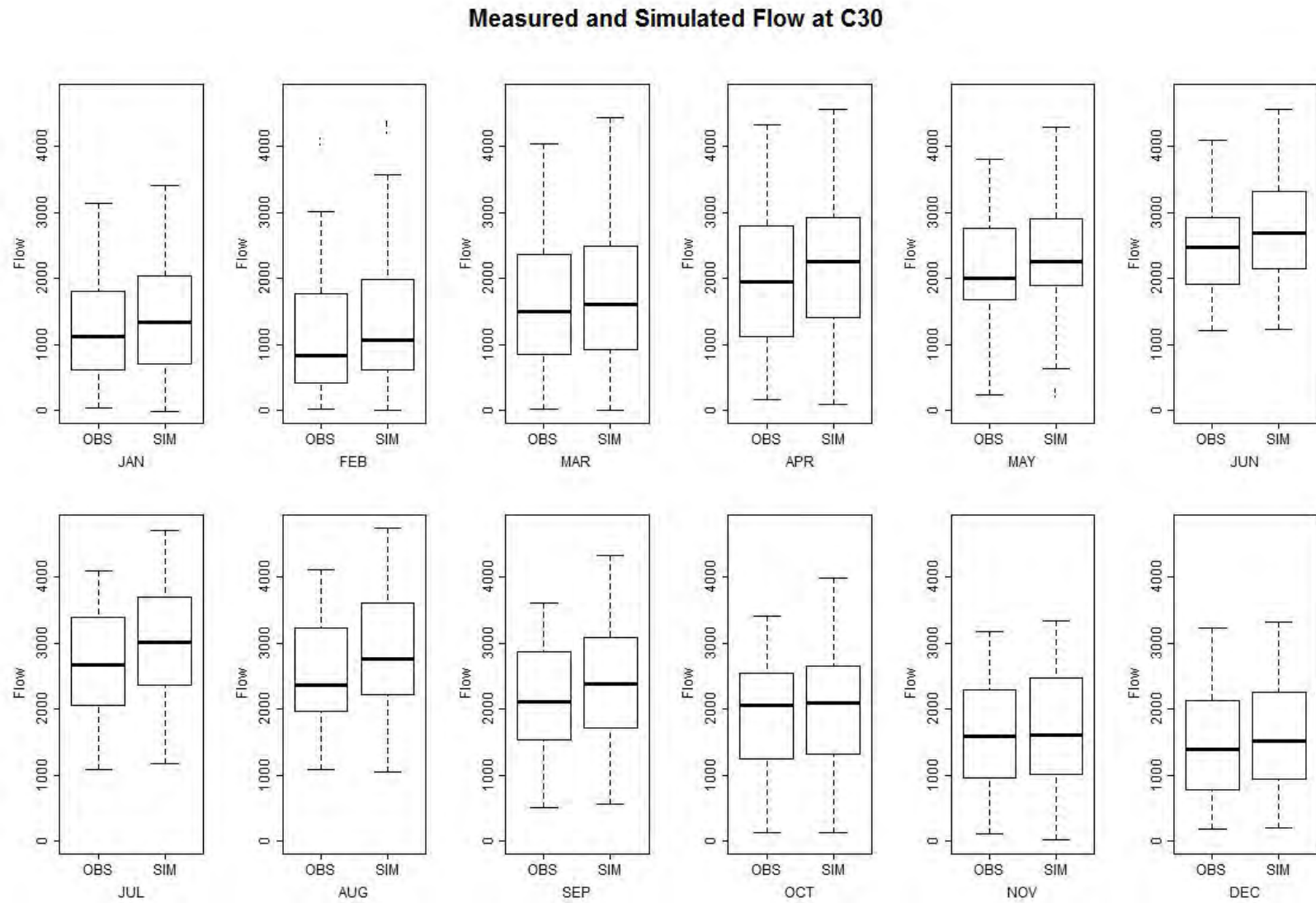


Figure 4.19 Month by Month Comparison of Measured and Simulated Flow at California Aqueduct Check 35

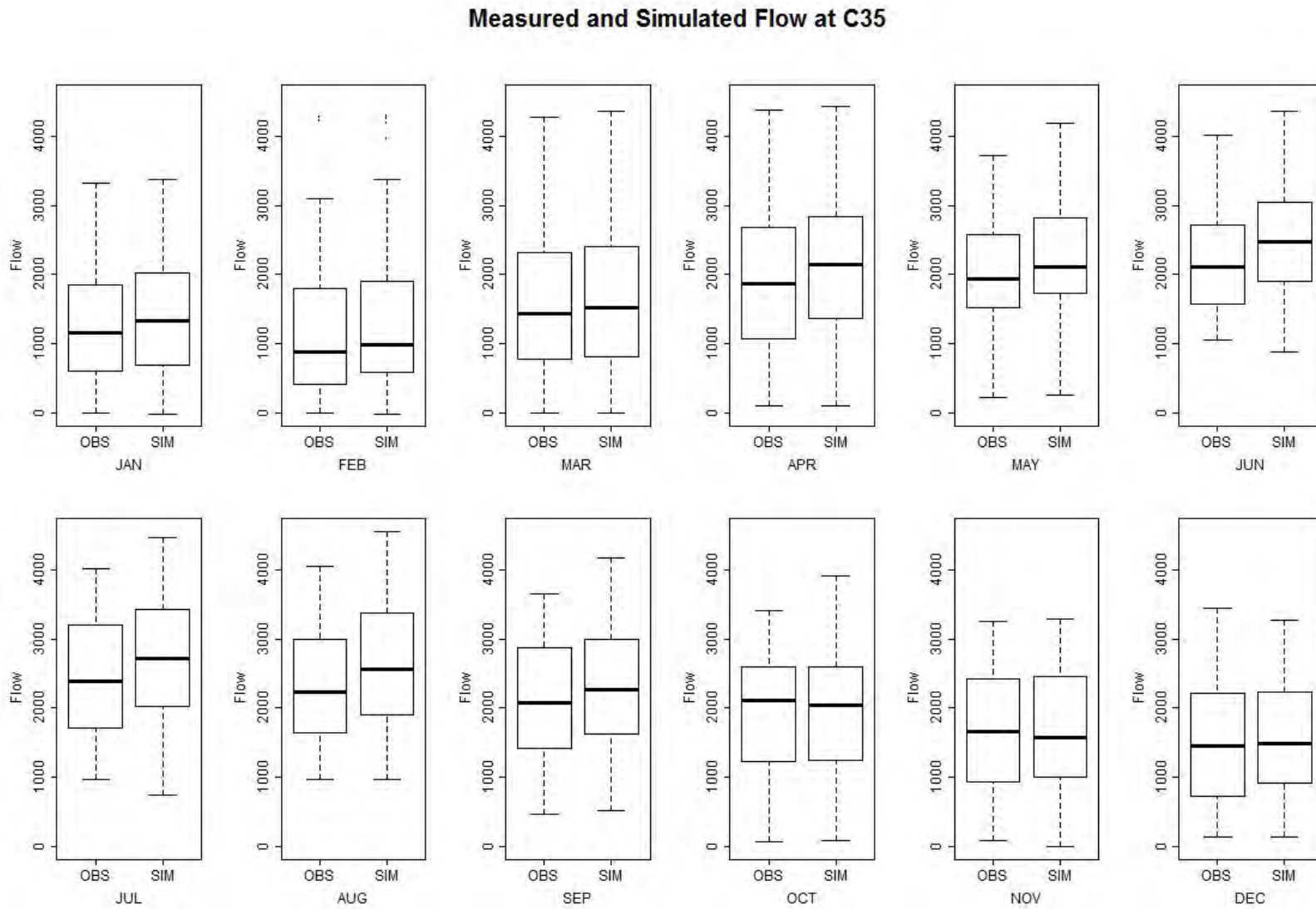


Figure 4.20 Month by Month Comparison of Measured and Simulated Flow at California Aqueduct Check 40

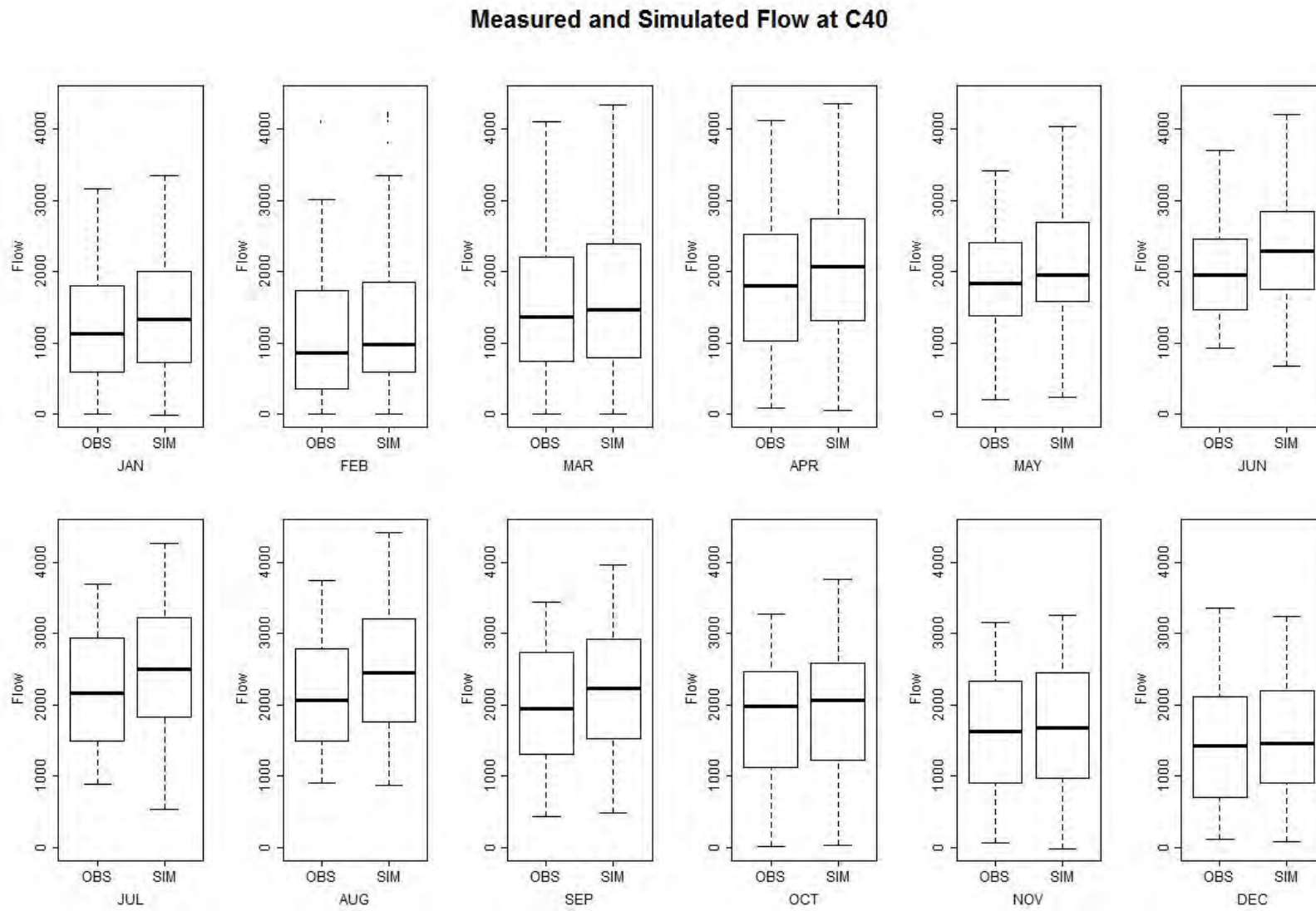


Figure 4.21 Month by Month Comparison of Measured and Simulated Flow at California Aqueduct Check 58

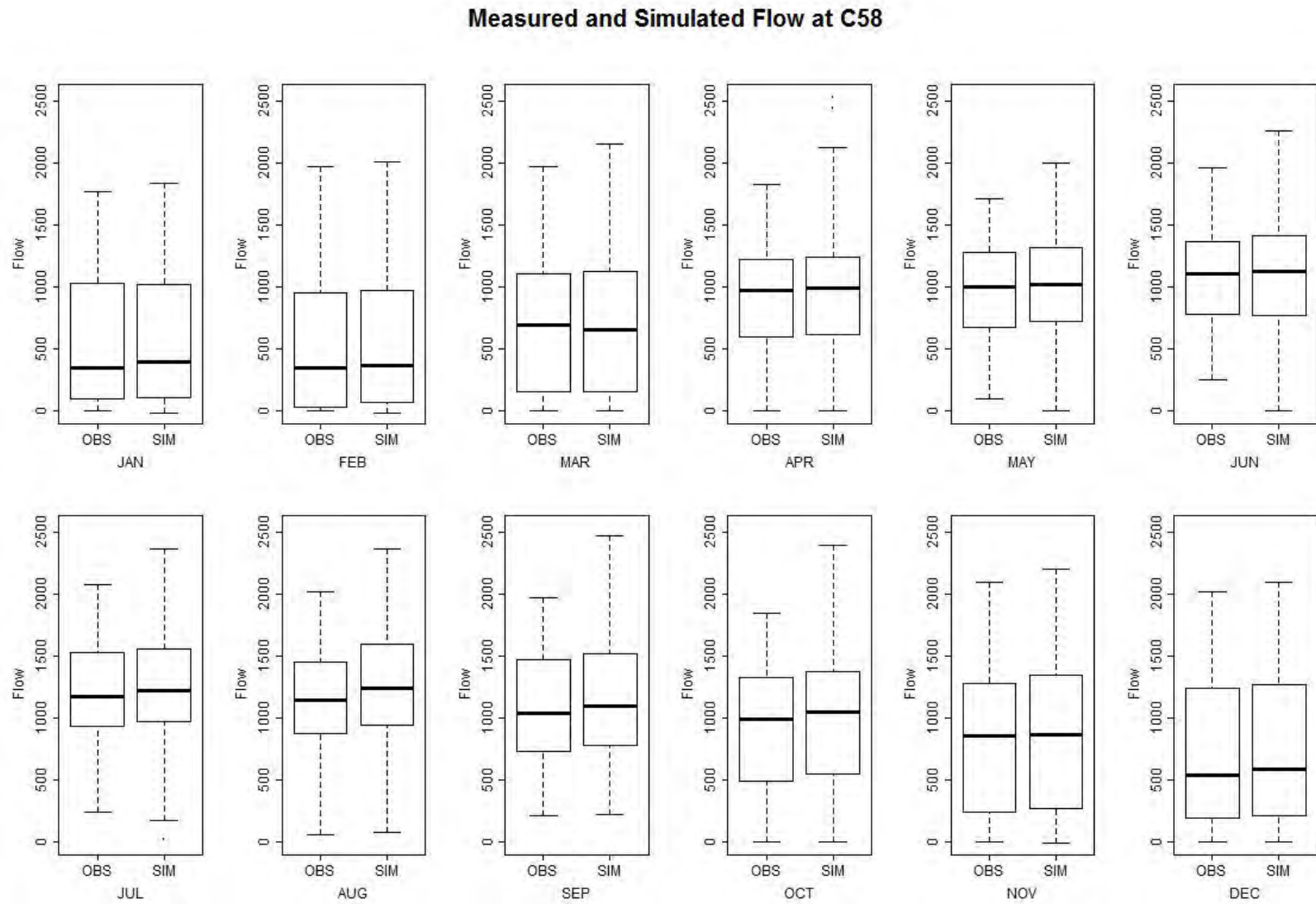


Figure 4.22 Comparison of Measured and Simulated EC at California Aqueduct Check 12

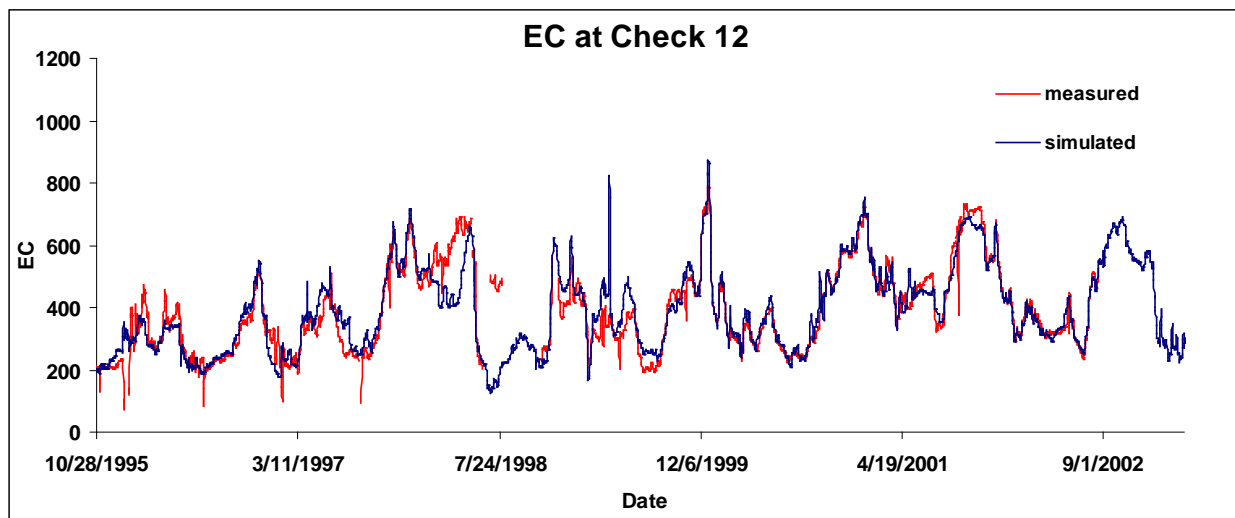
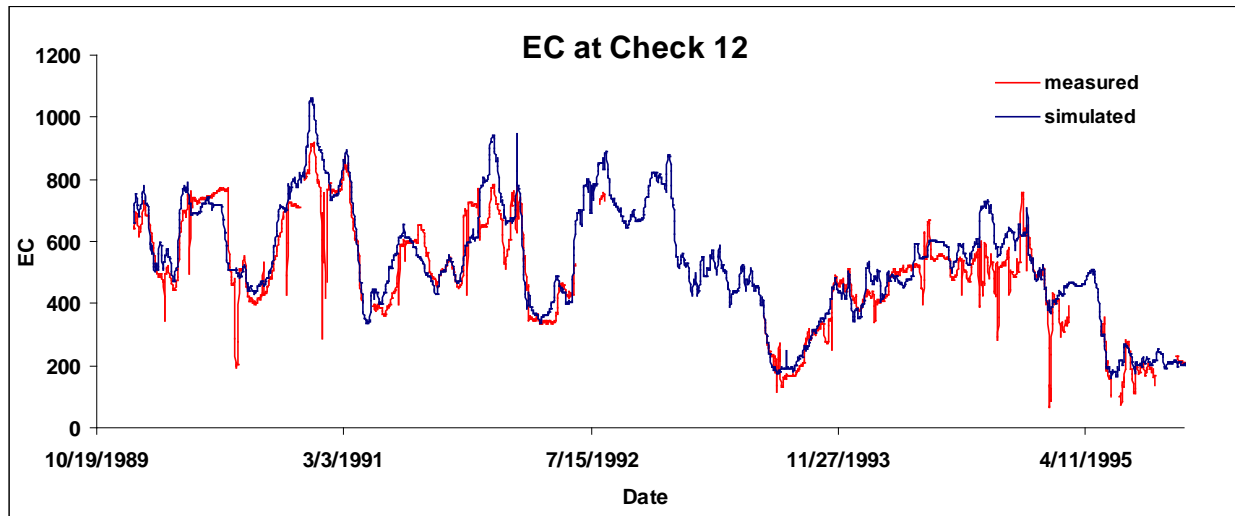


Figure 4.23 Comparison of Measured and Simulated EC at California Aqueduct Check 13

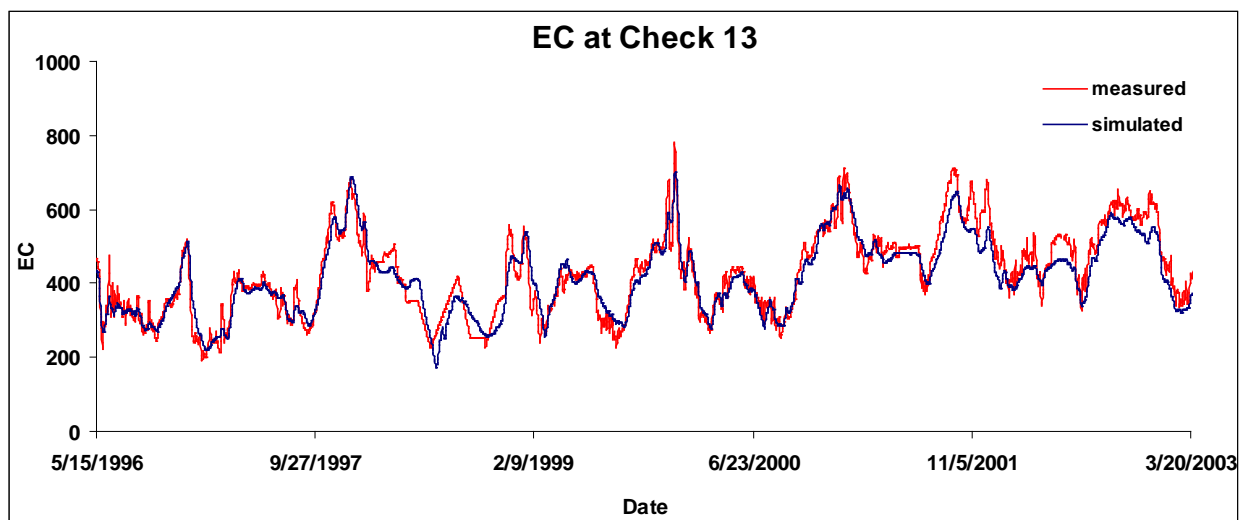
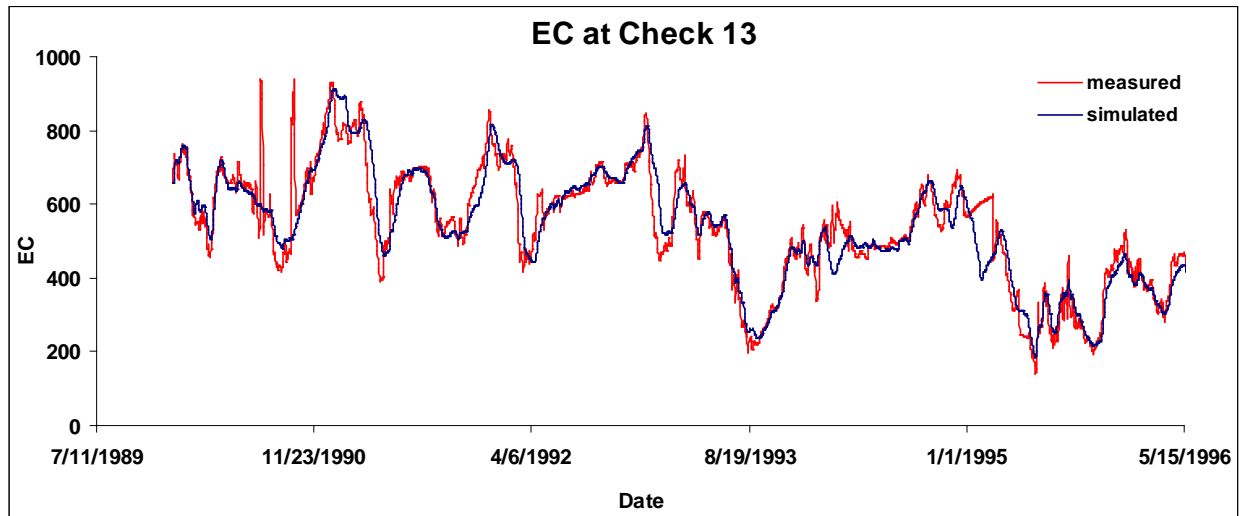


Figure 4.24 Comparison of Measured and Simulated EC at California Aqueduct Check 18

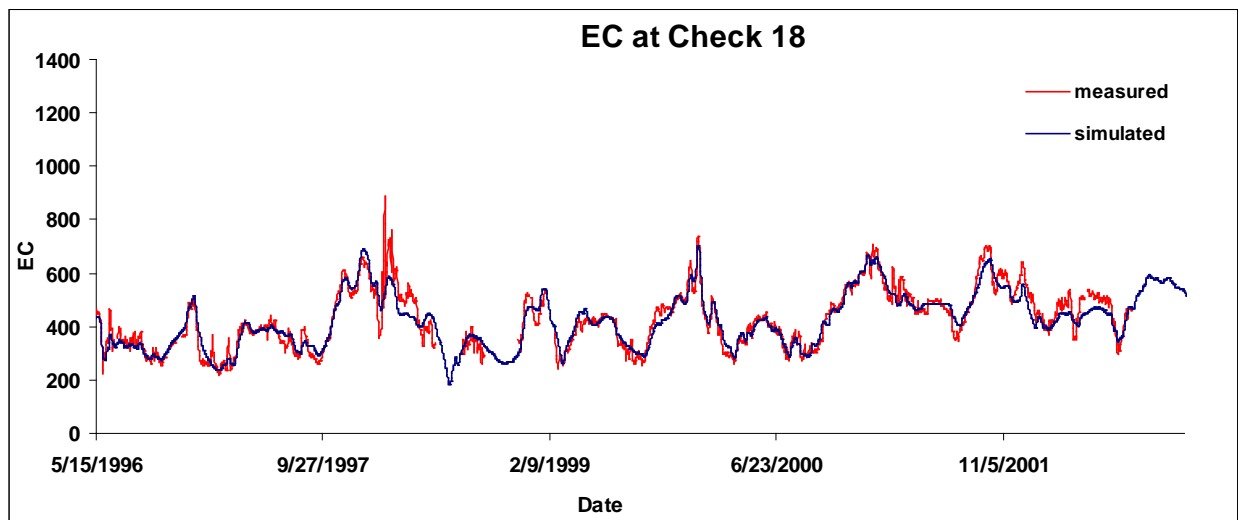
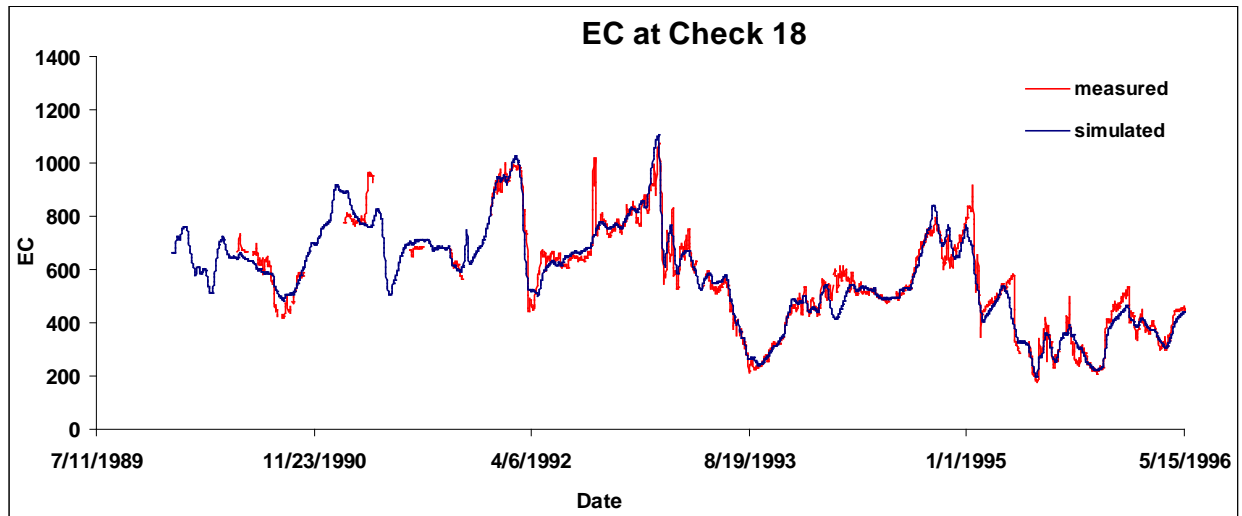


Figure 4.25 Comparison of Measured and Simulated EC at California Aqueduct Check 21

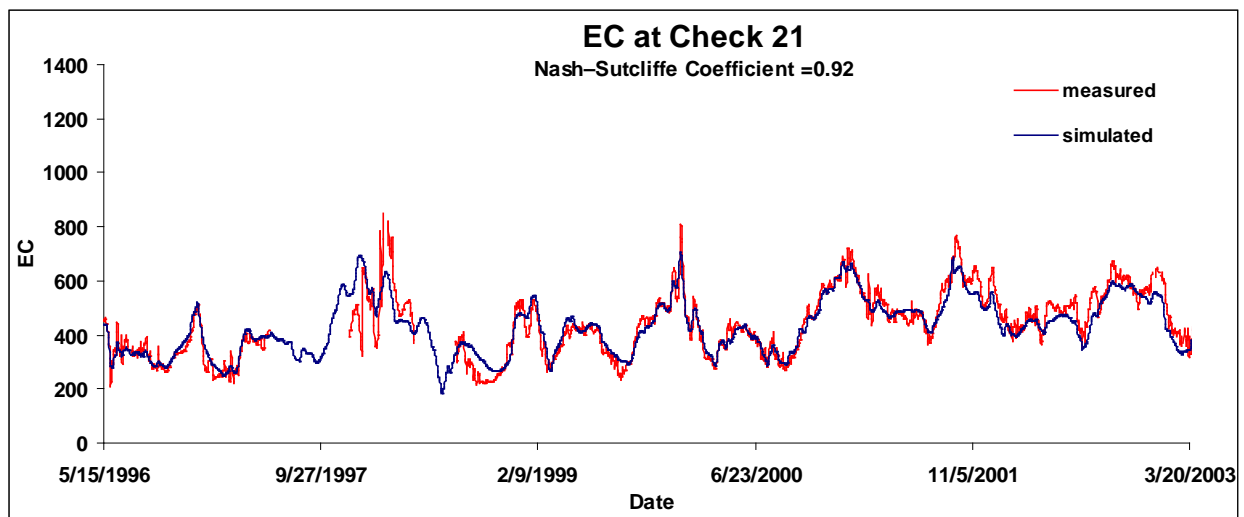
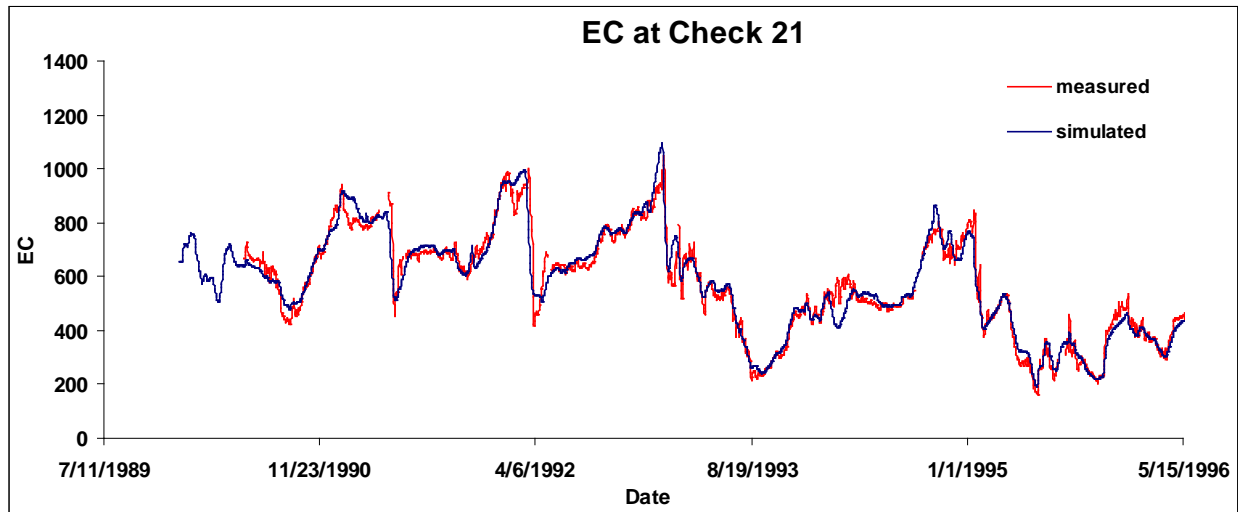


Figure 4.26 Comparison of Measured and Simulated EC at California Aqueduct Check 29

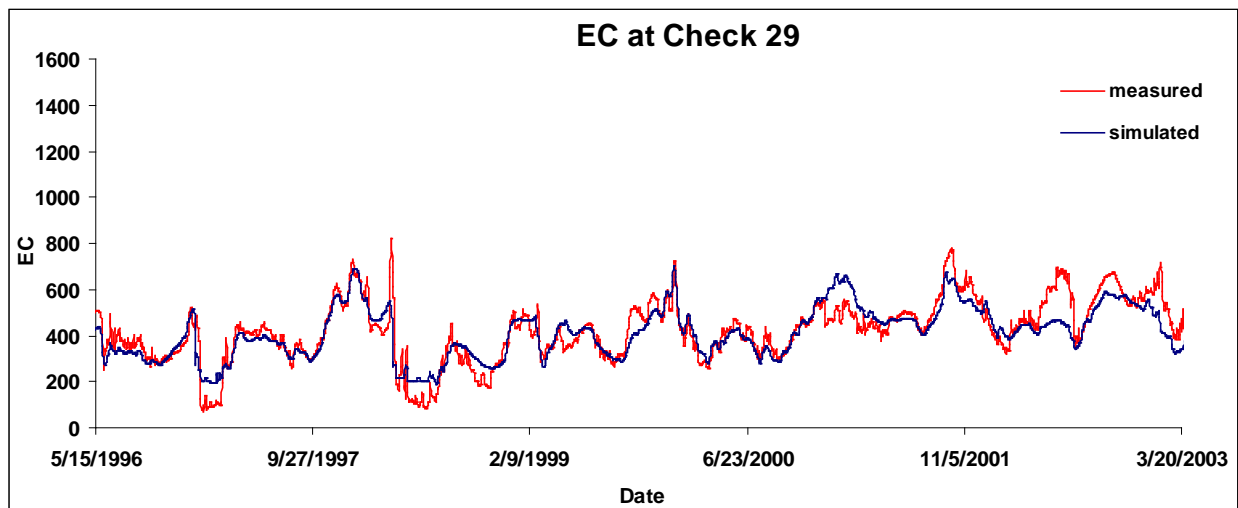
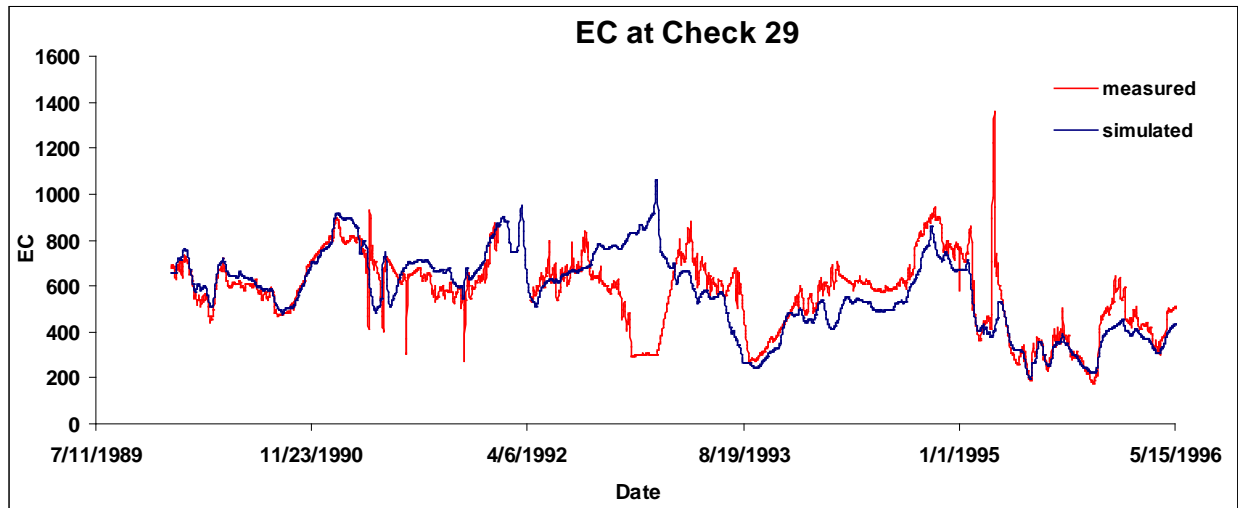


Figure 4.27 Comparison of Measured and Simulated EC at California Aqueduct Check 41

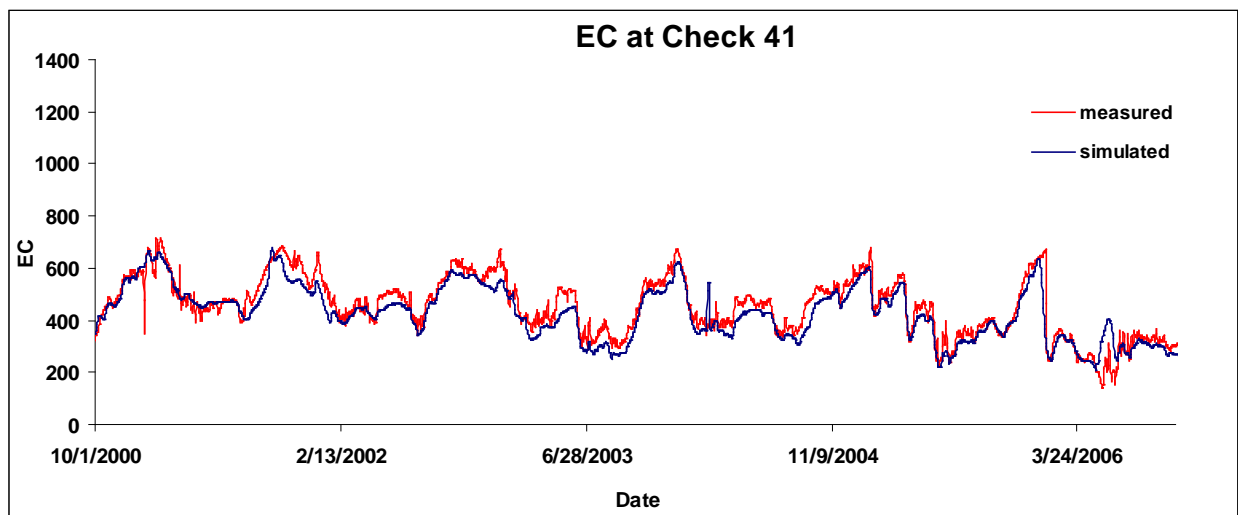
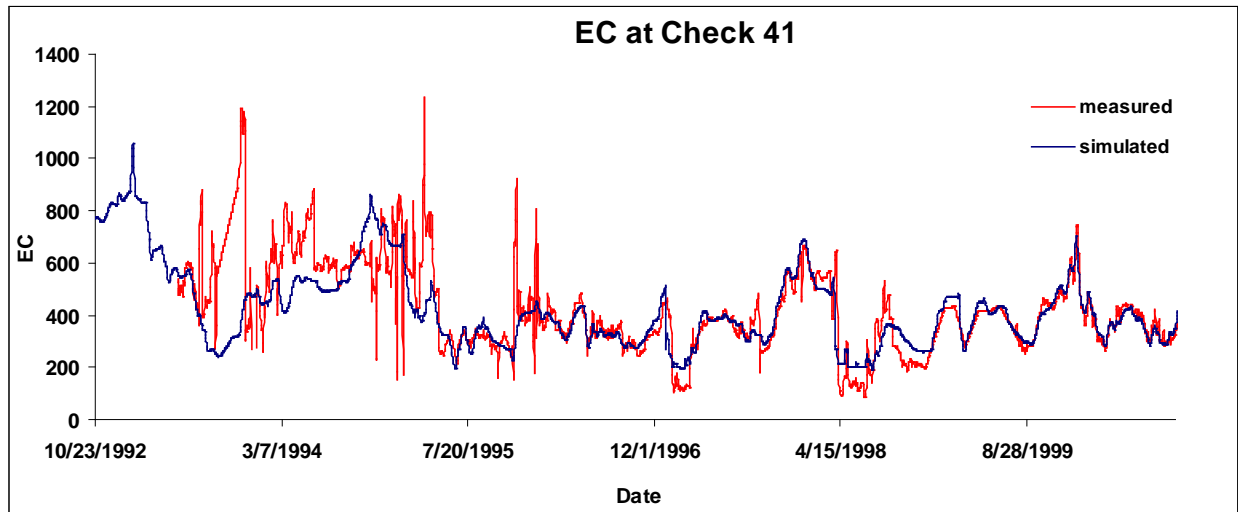


Figure 4.28 Comparison of Measured and Simulated EC at California Aqueduct Check 66

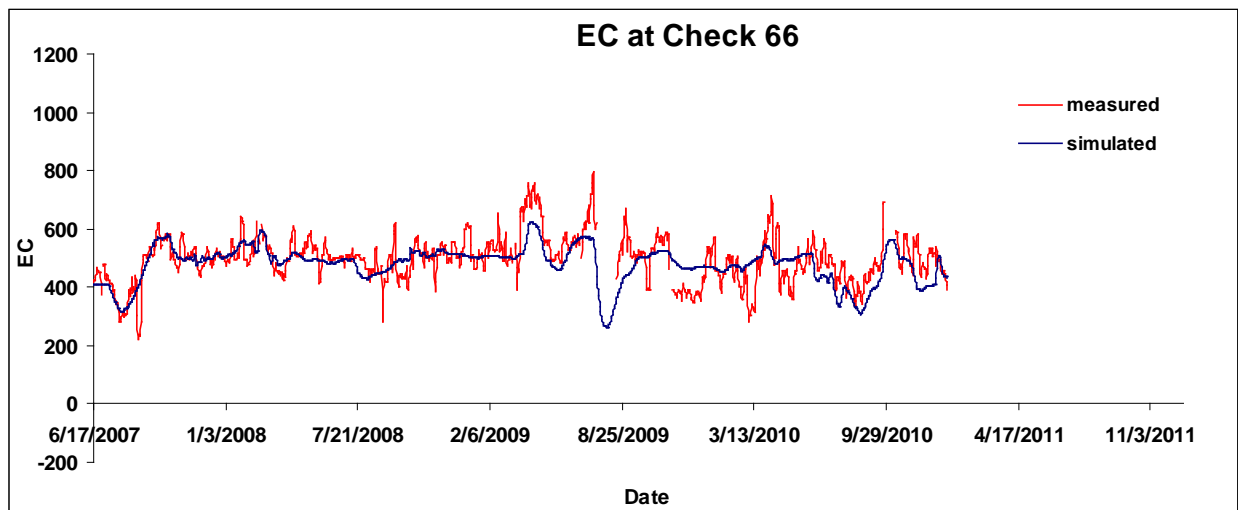
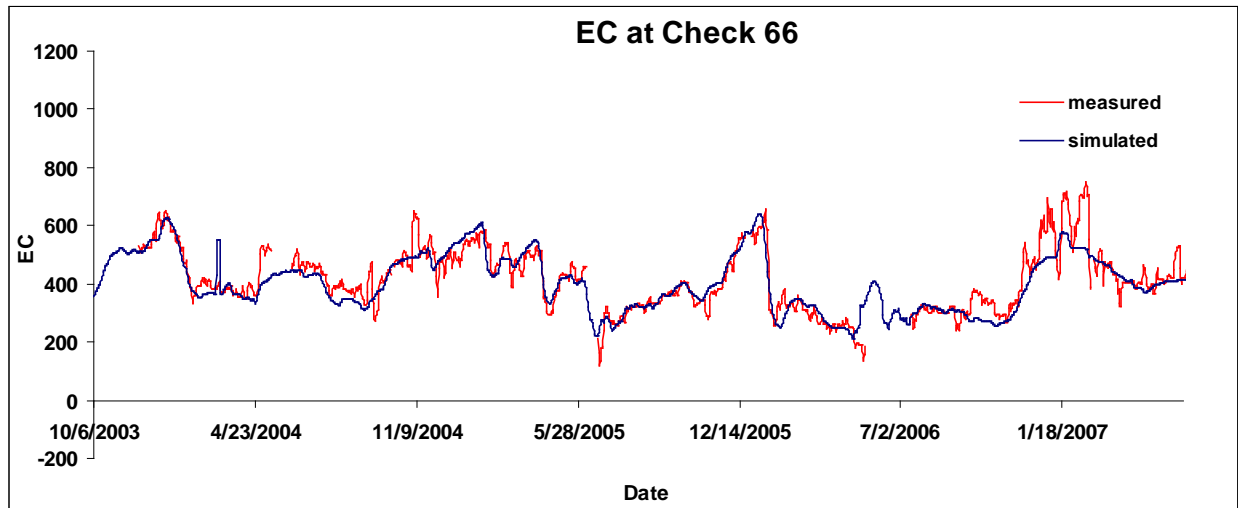




Figure 4.29 Comparison of Measured and Simulated EC at DMC Check 13

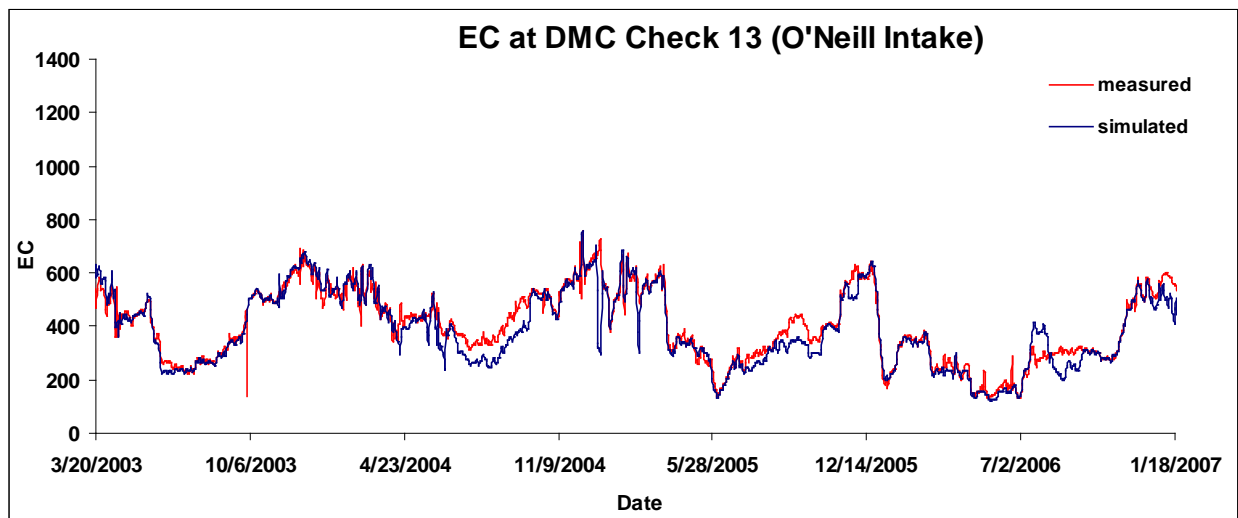
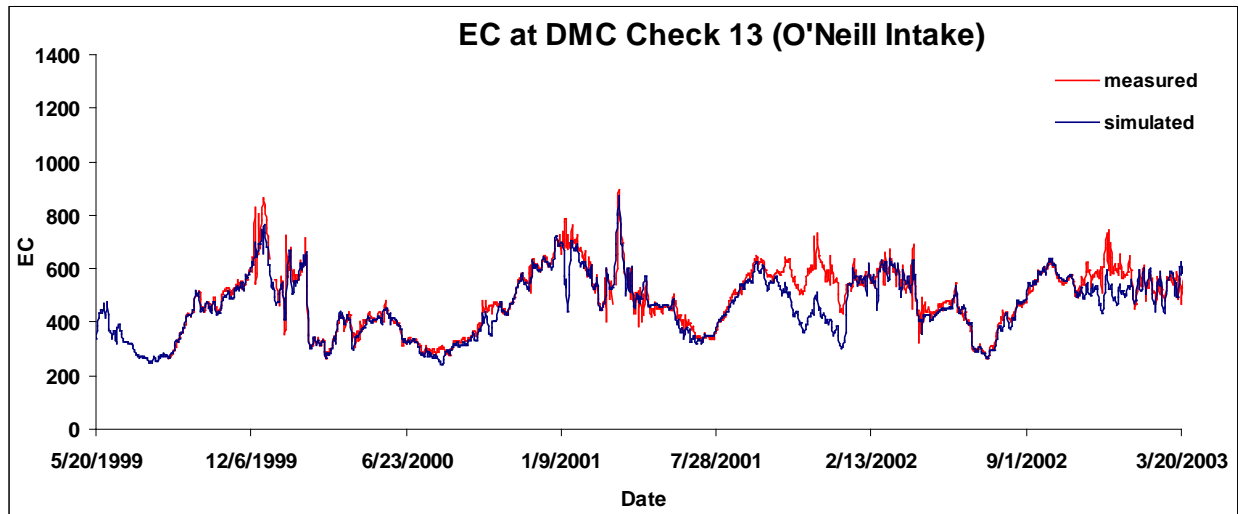


Figure 4.30 Comparison of Measured and Simulated EC at DMC Check 20

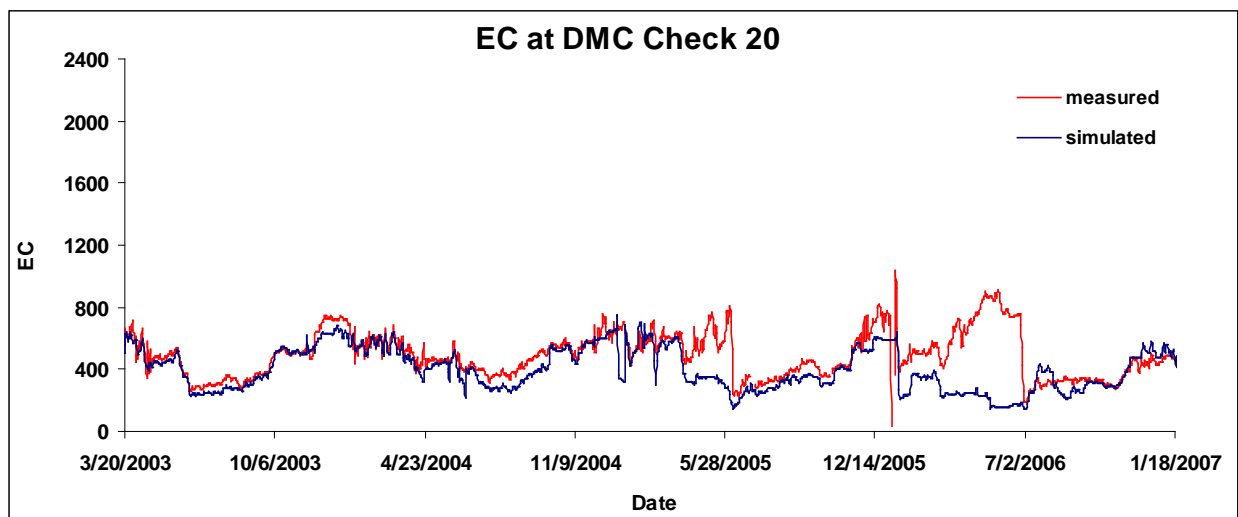
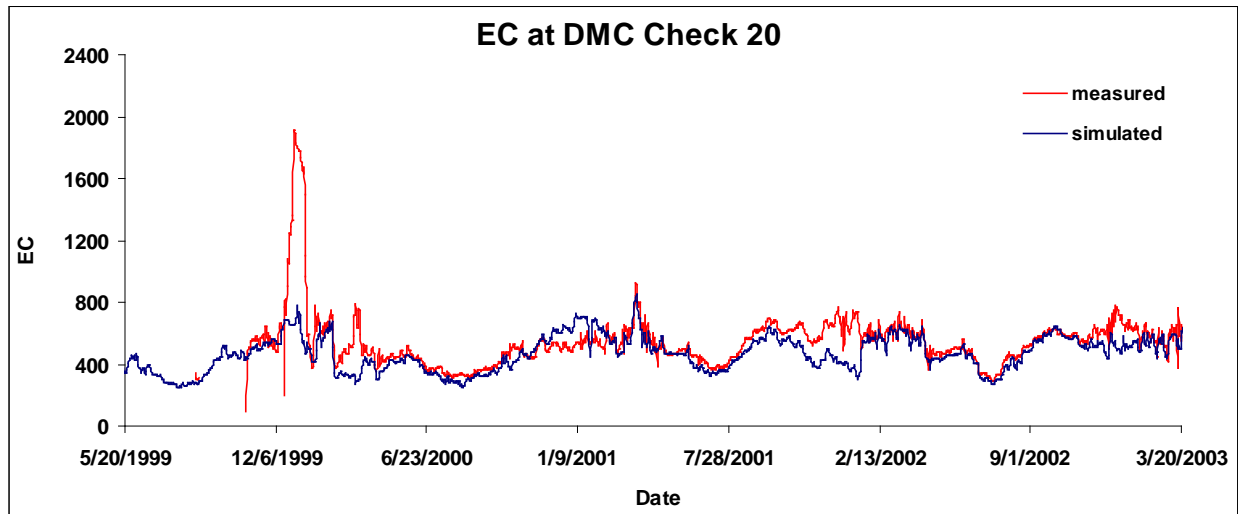


Figure 4.31 Comparison of Measured and Simulated EC at DMC Check 21

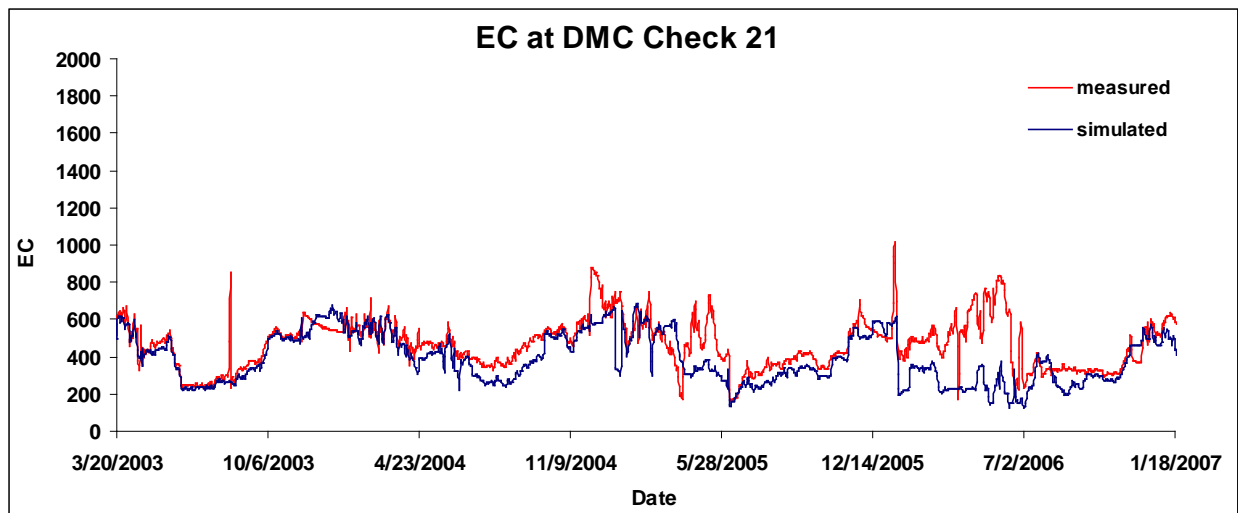
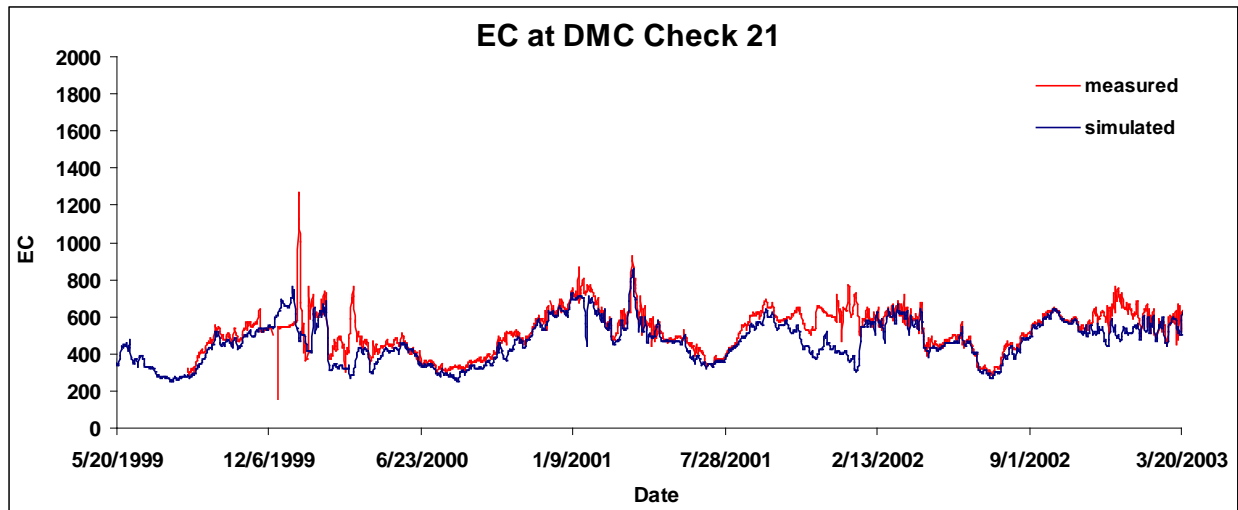


Figure 4.32 Comparison of Measured and Simulated EC at San Luis Reservoir

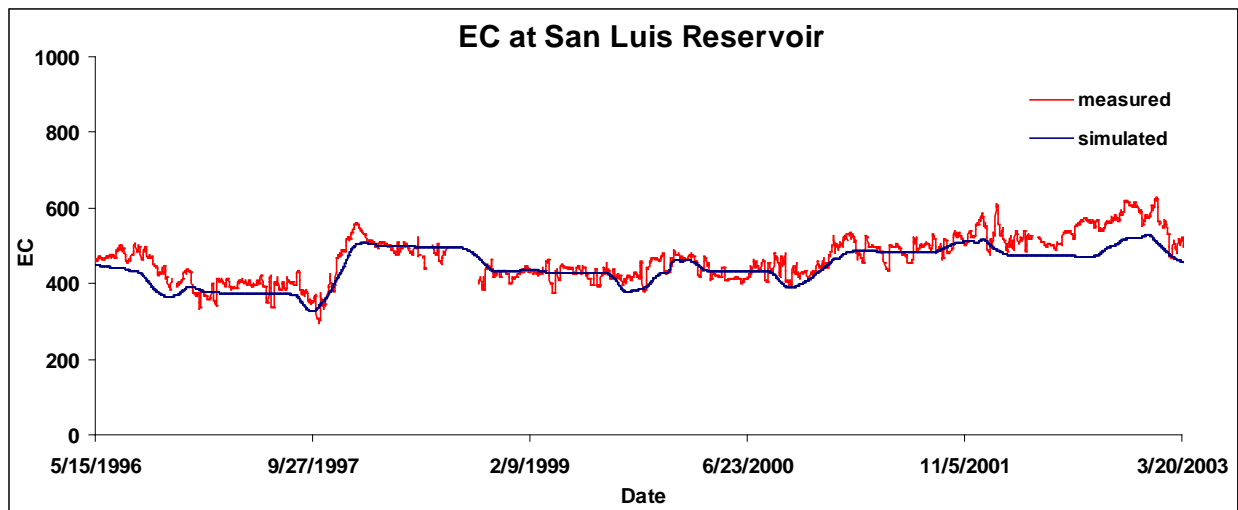
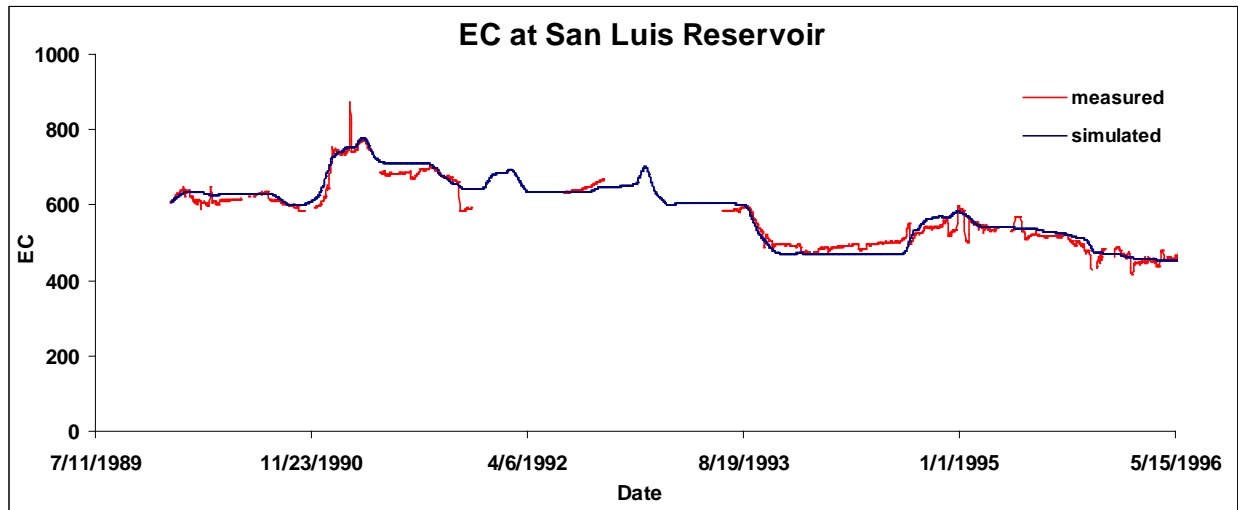


Figure 4.33 Comparison of Measured and Simulated EC at Del Valle Check 7, South Bay Aqueduct

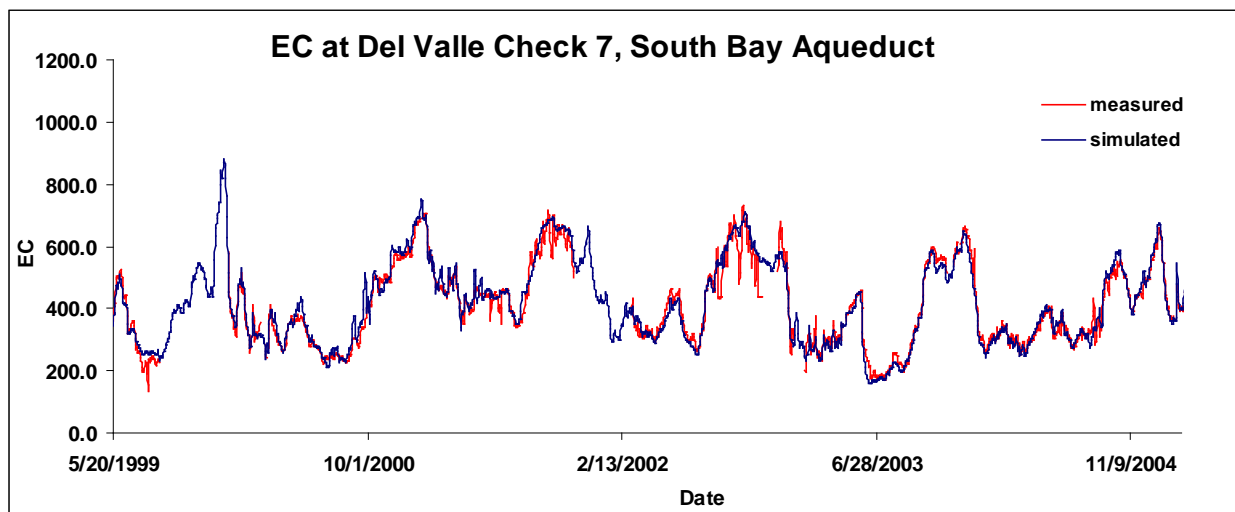
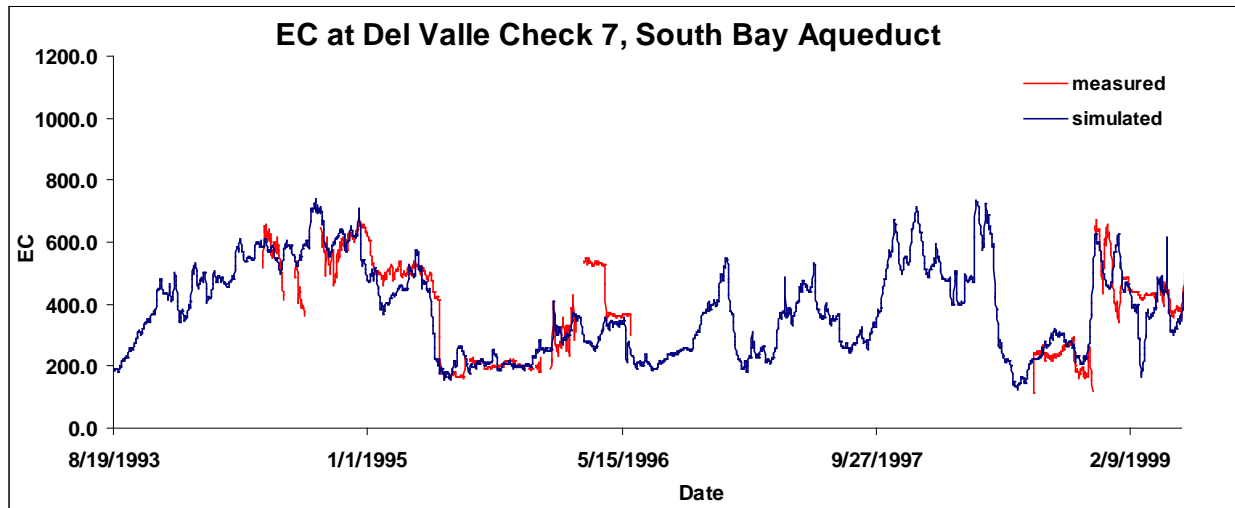


Figure 4.34 Scatter Plot for EC at California Aqueduct Check 12

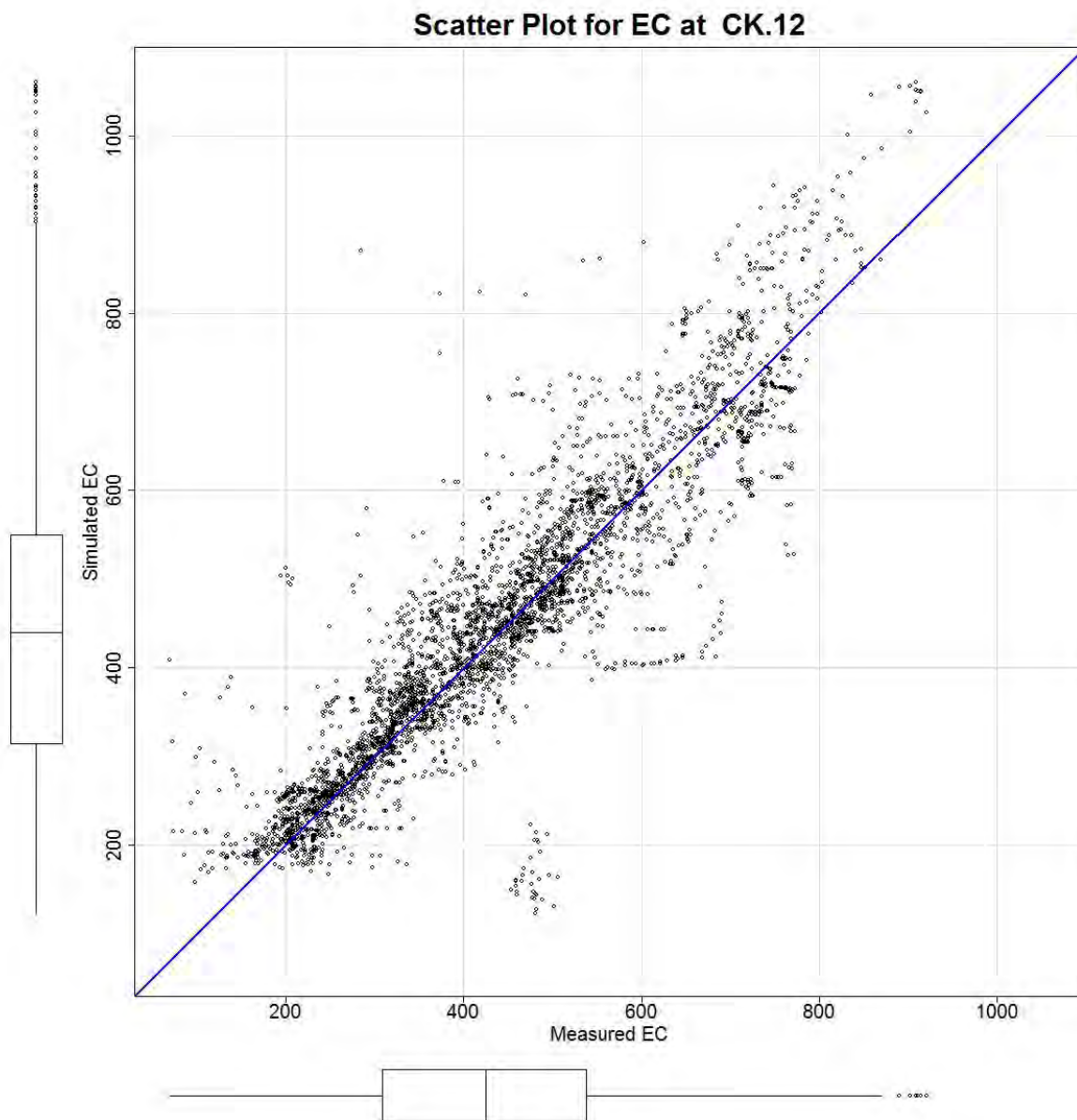


Figure 4.35 Scatter Plot for EC at California Aqueduct Check 13

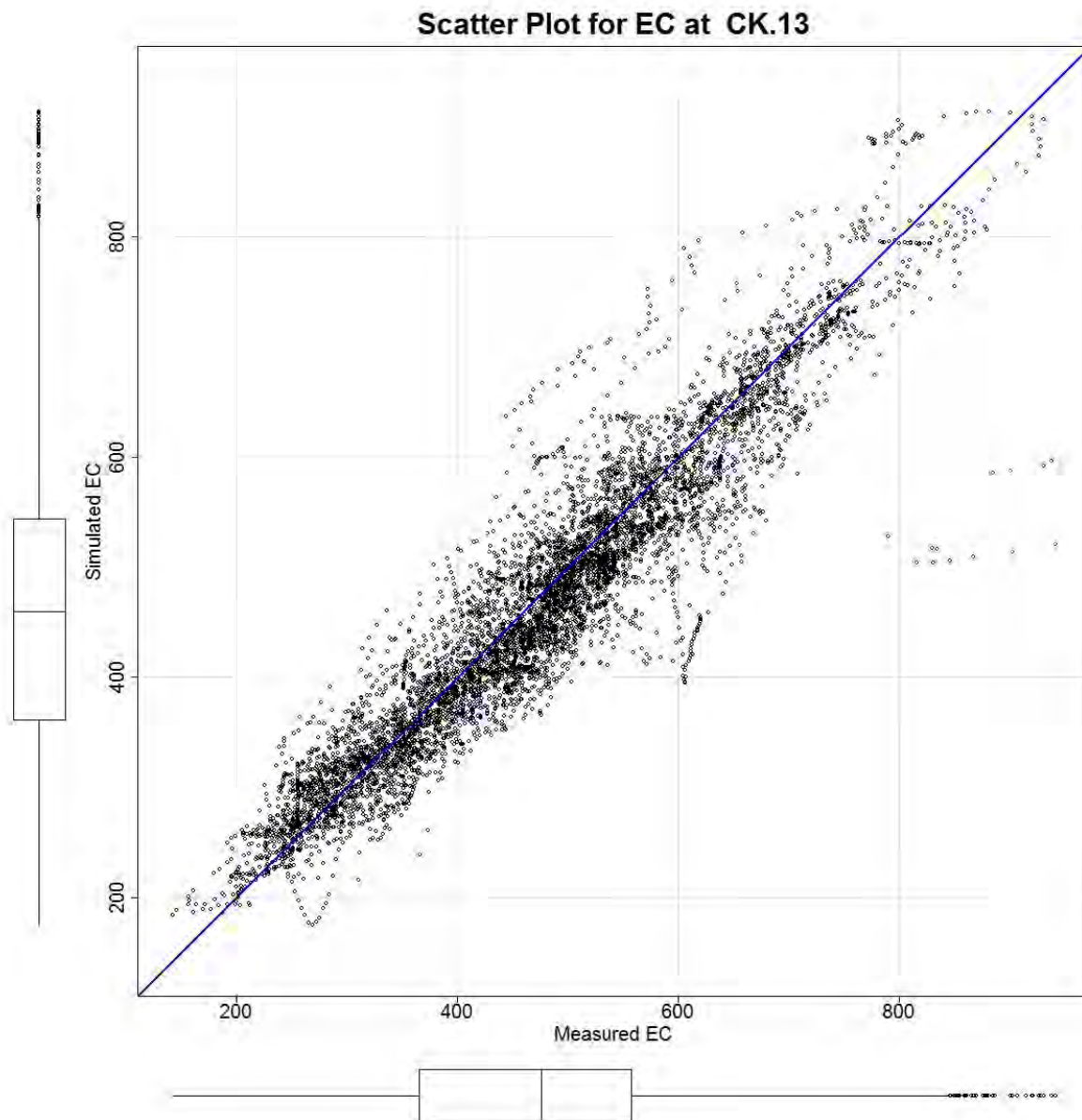


Figure 4.36 Scatter Plot for EC at California Aqueduct Check 18

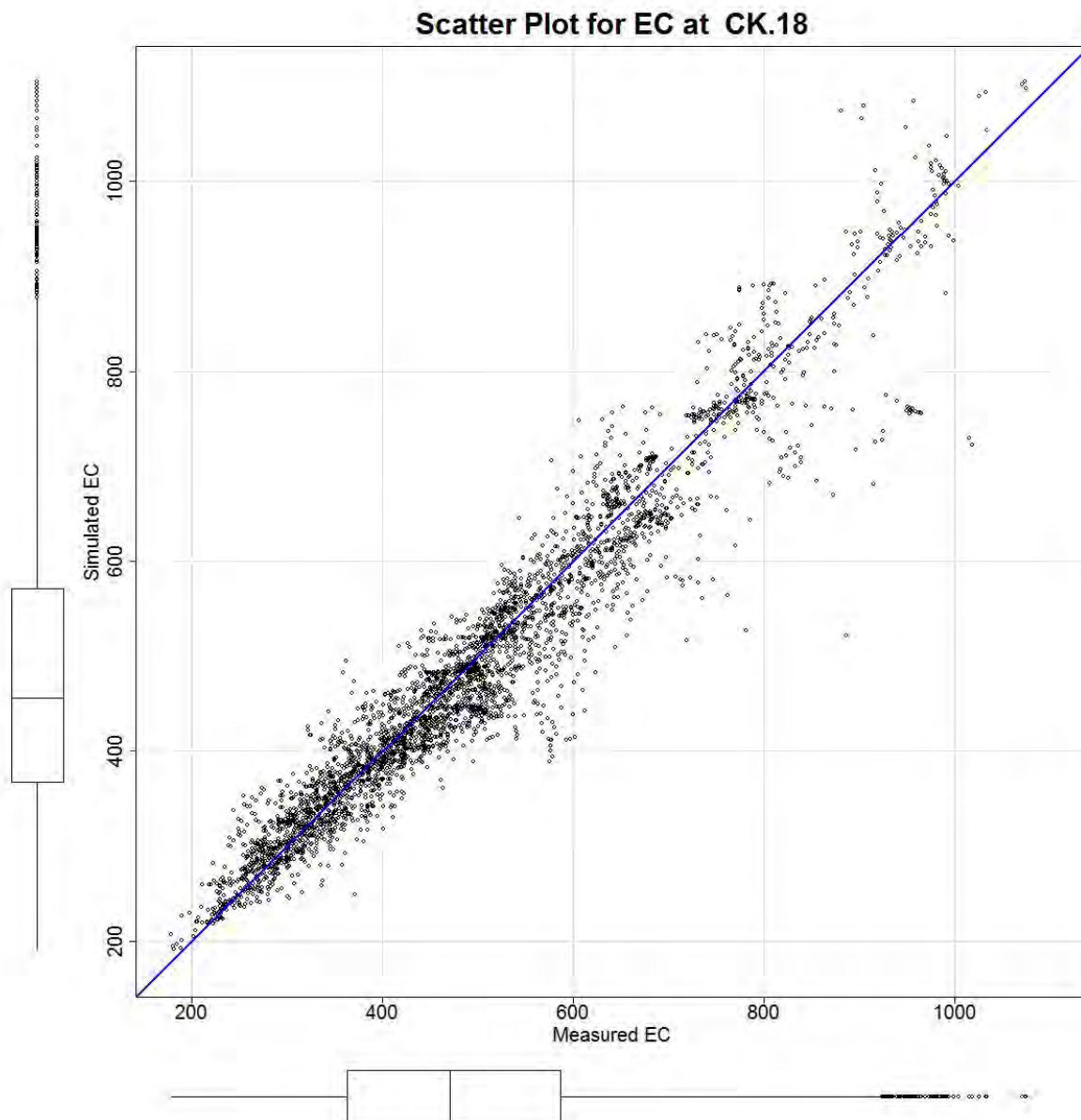


Figure 4.37 Scatter Plot for EC at California Aqueduct Check 21

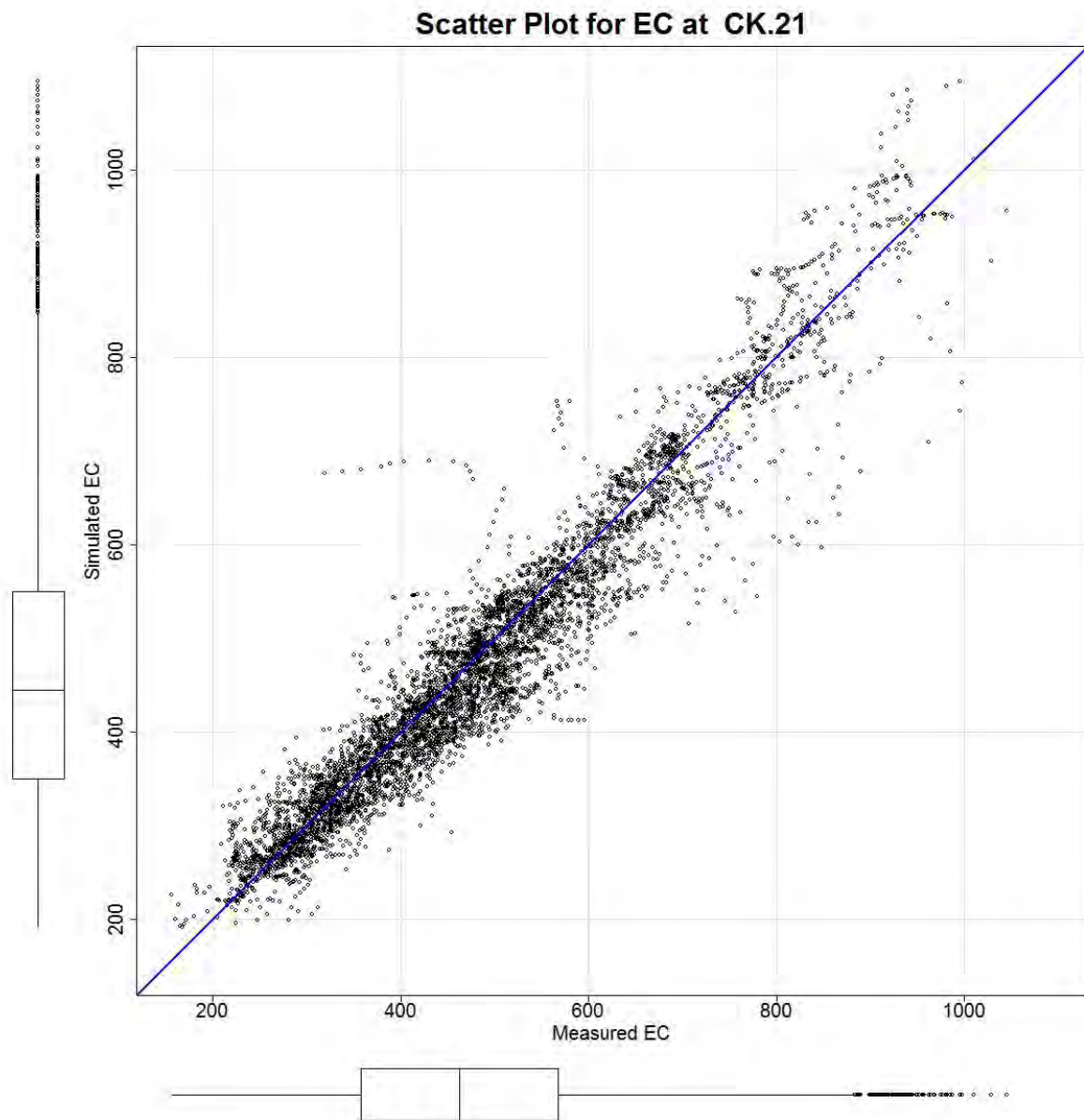


Figure 4.38 Scatter Plot for EC at California Aqueduct Check 29

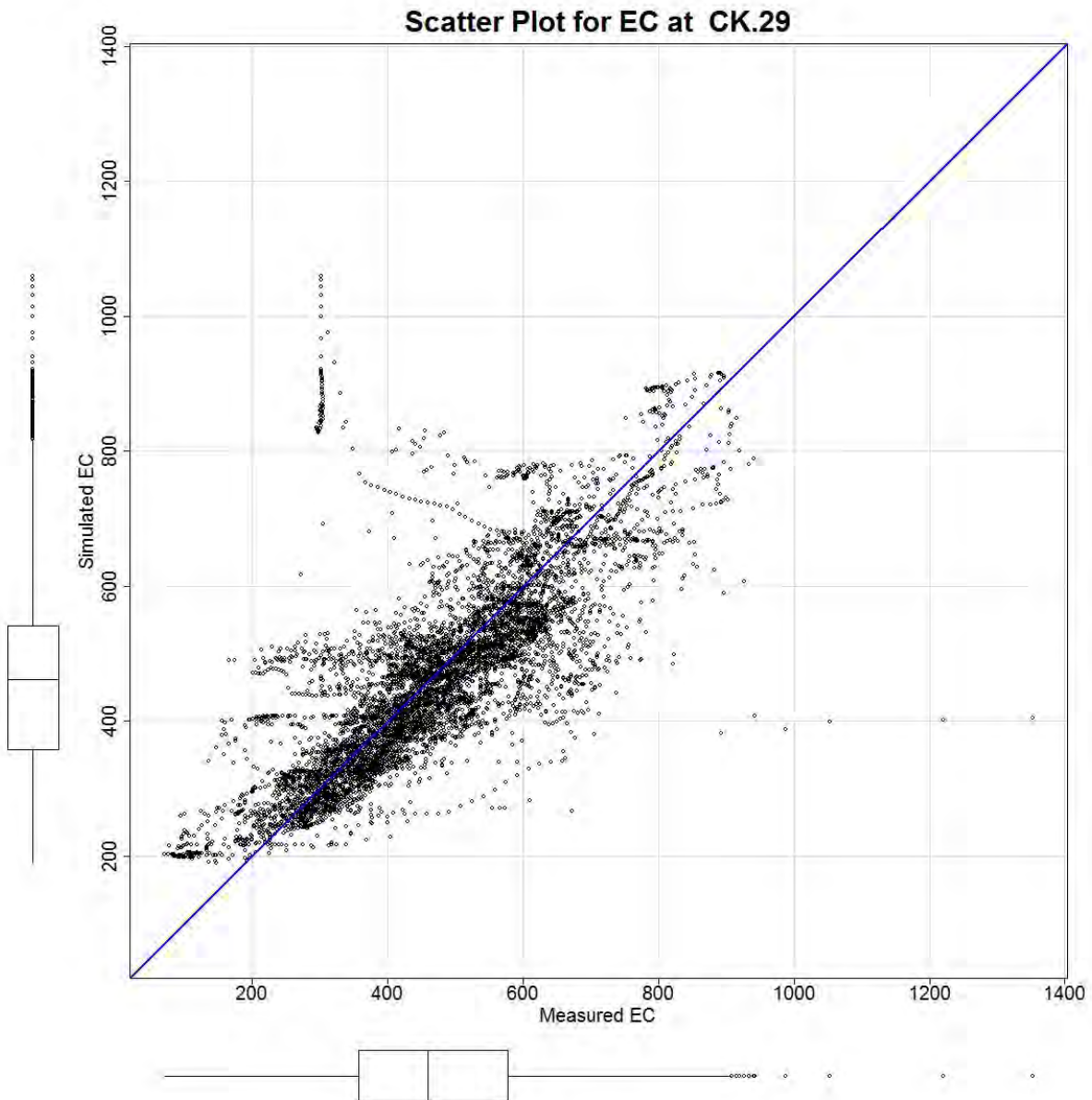


Figure 4.39 Scatter Plot for EC at California Aqueduct Check 41

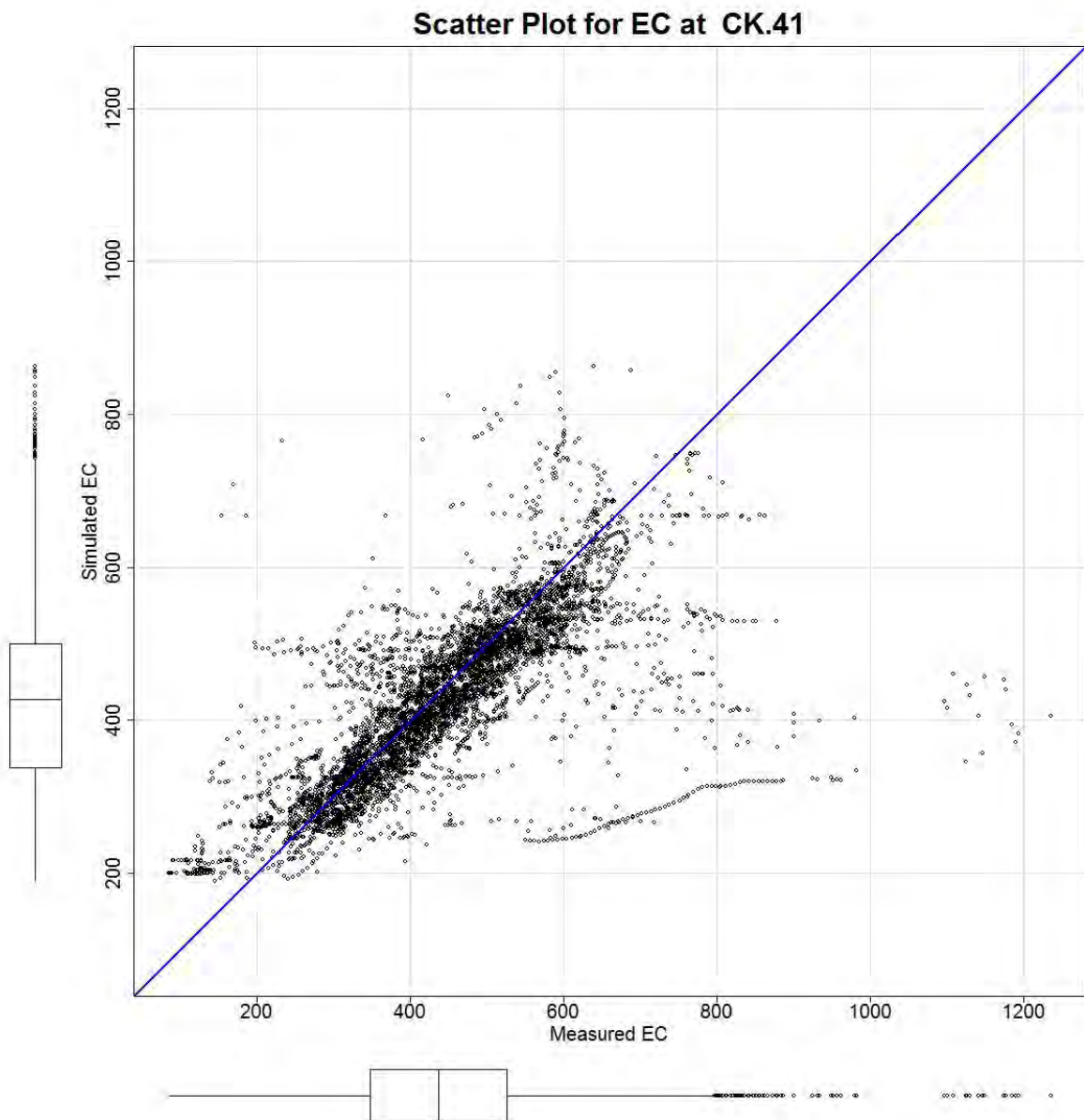


Figure 4.40 Scatter Plot for EC at California Aqueduct Check 66

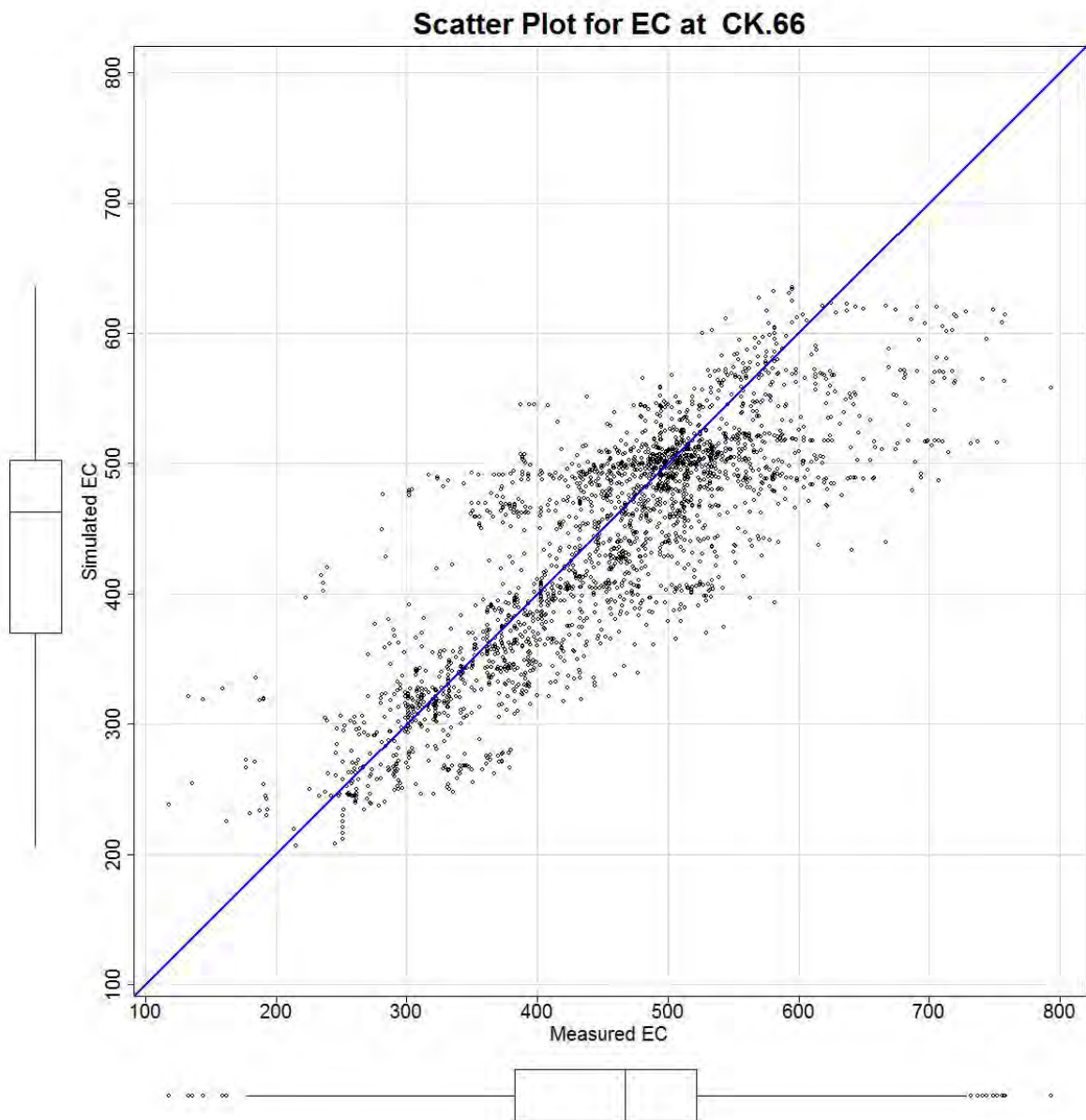


Figure 4.41 Scatter Plot for EC at Del Valle Check 7, South Bay Aqueduct

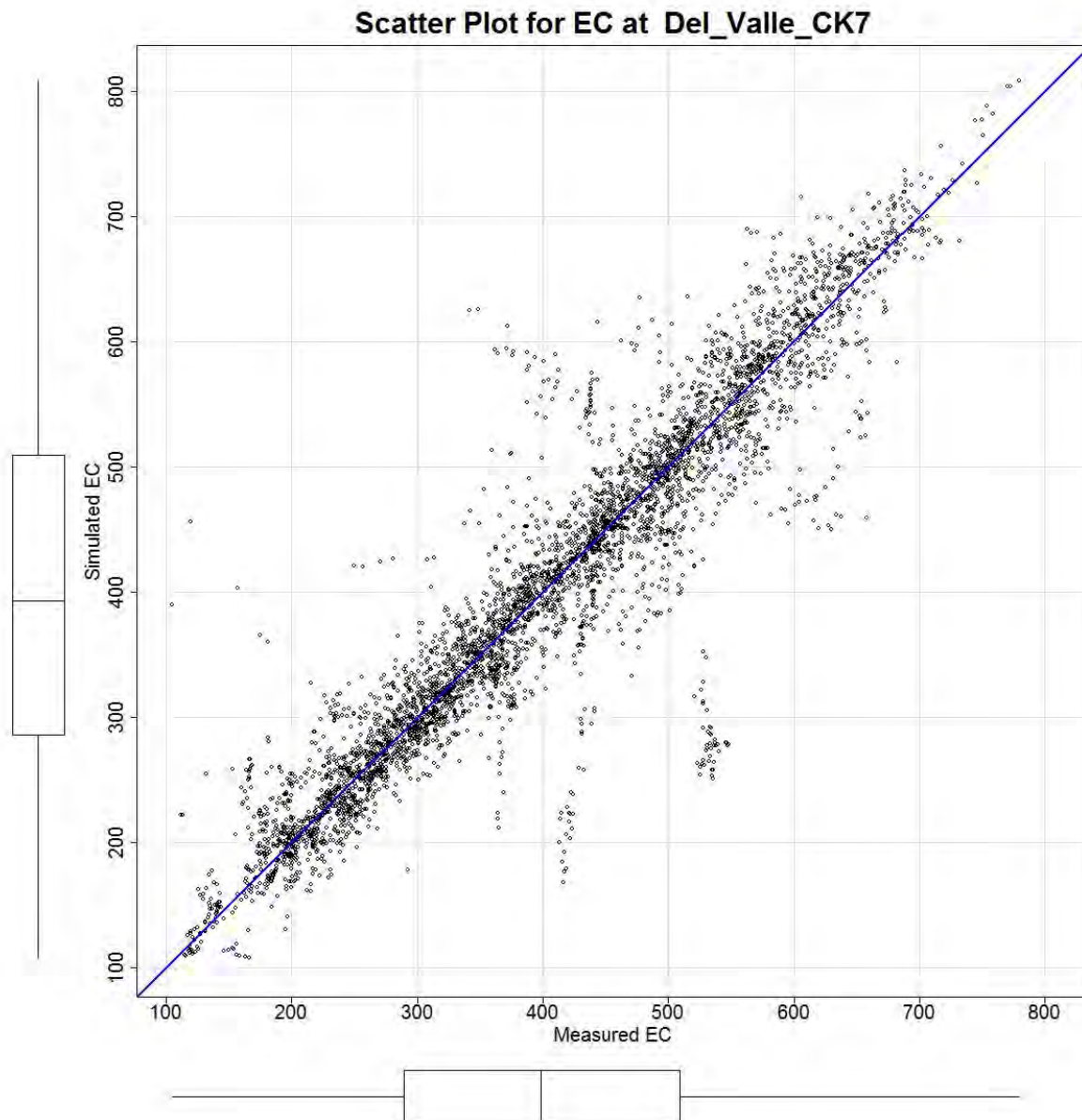


Figure 4.42 Scatter Plot for EC at DMC Check 13

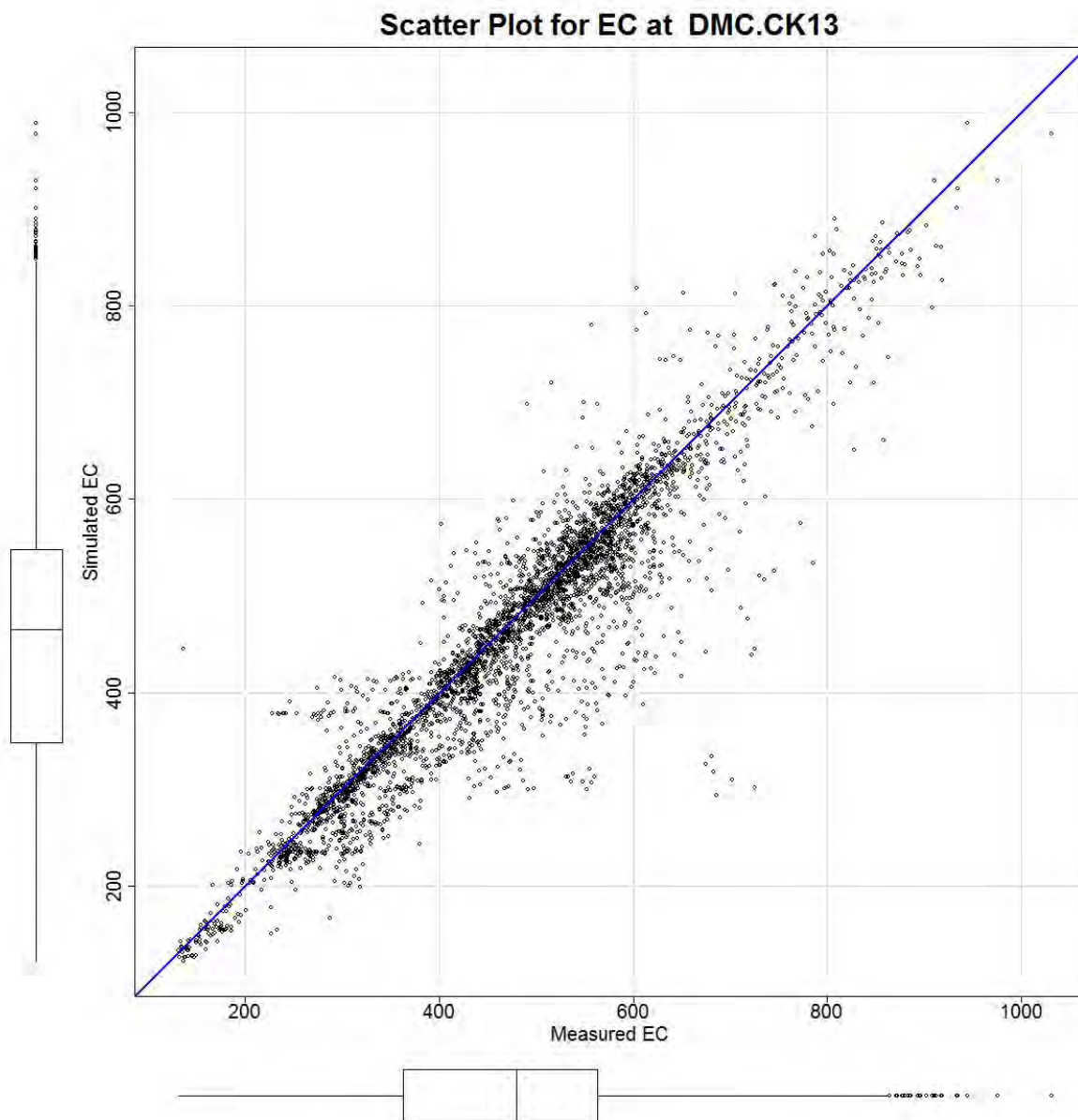


Figure 4.43 Scatter Plot for EC at DMC Check 20

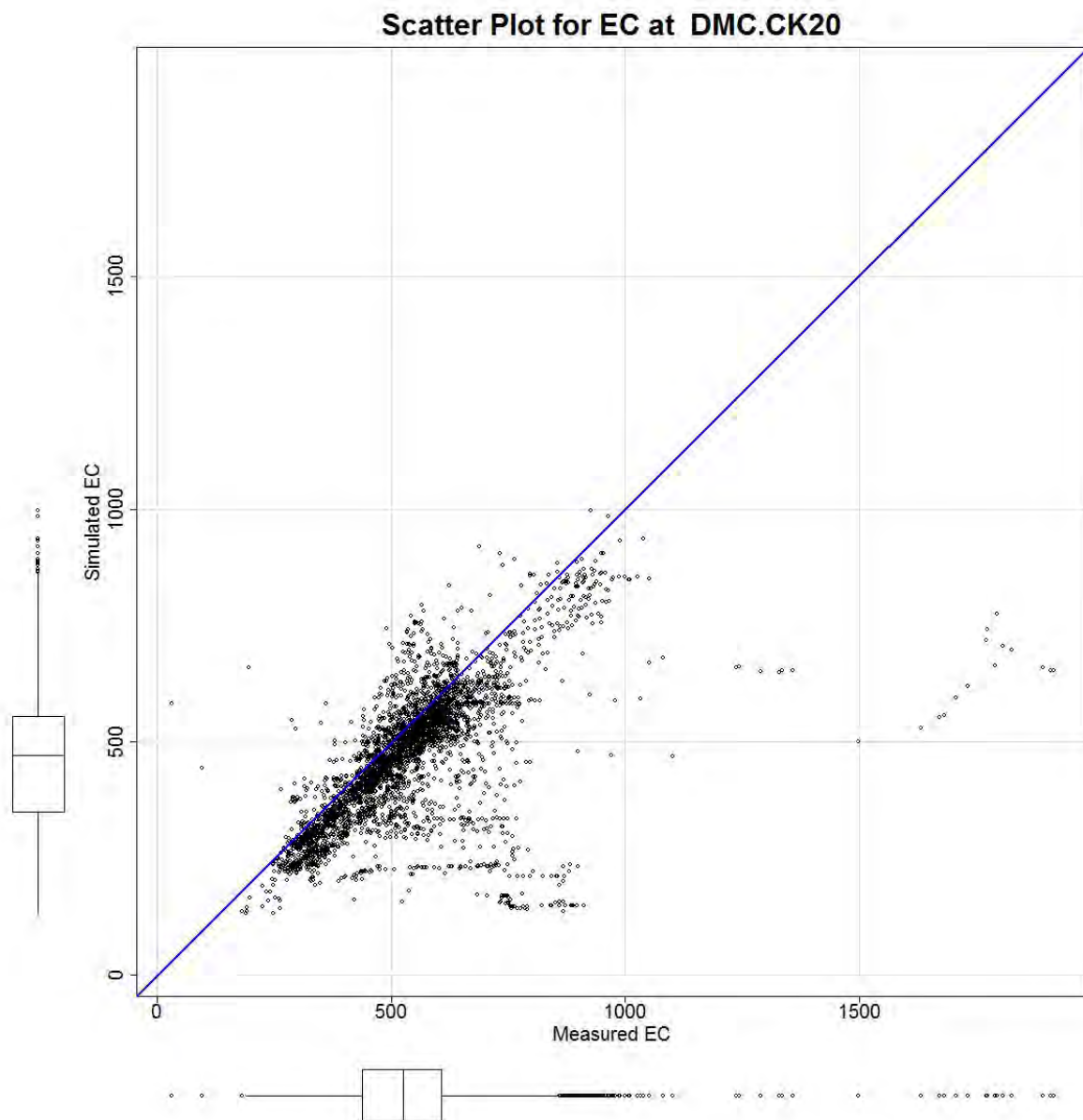


Figure 4.44 Scatter Plot for EC at DMC Check 21

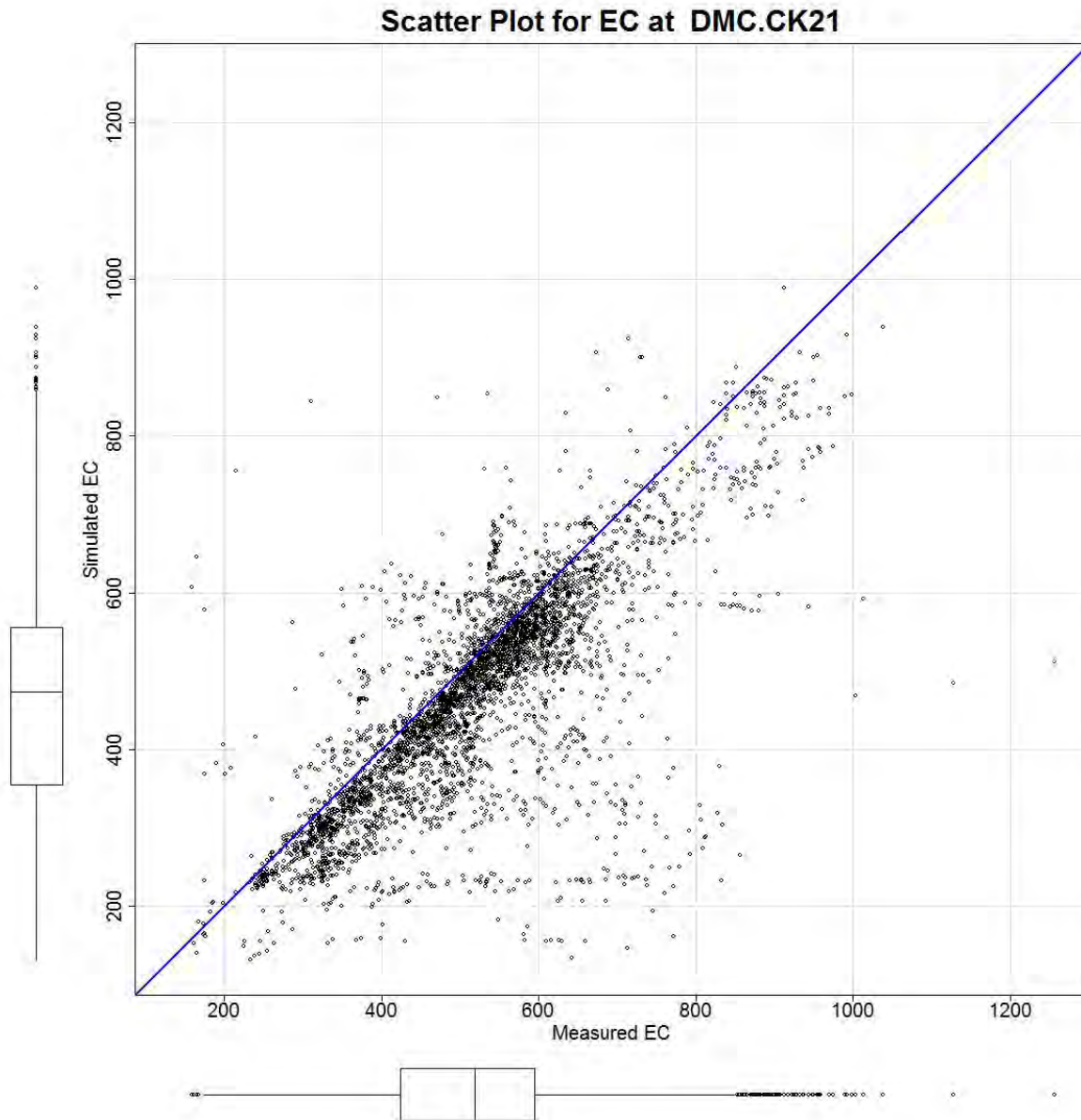


Figure 4.45 Scatter Plot for EC at San Luis Reservoir

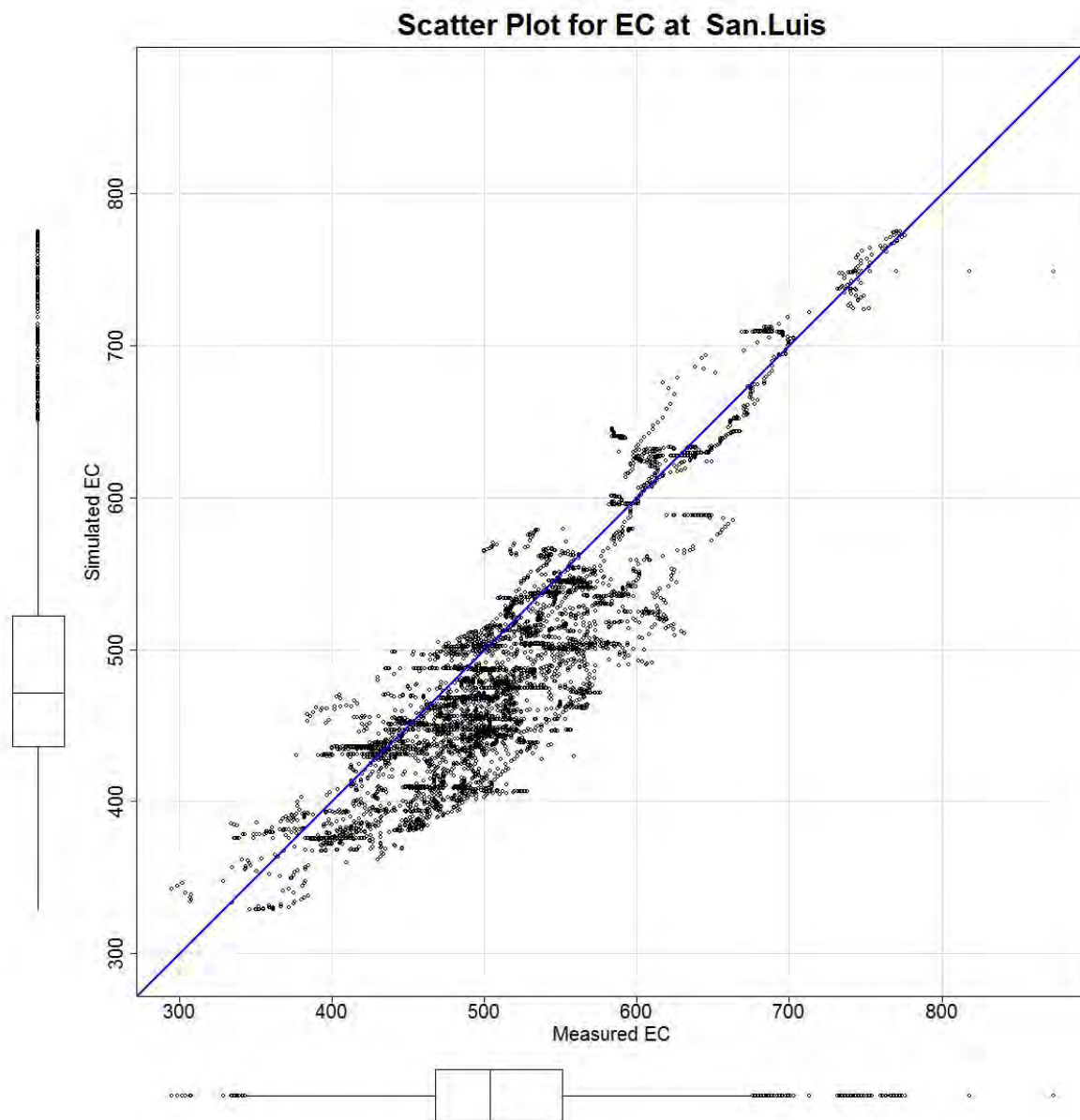


Figure 4.46 Exceedance Curve for EC at California Aqueduct Check 12

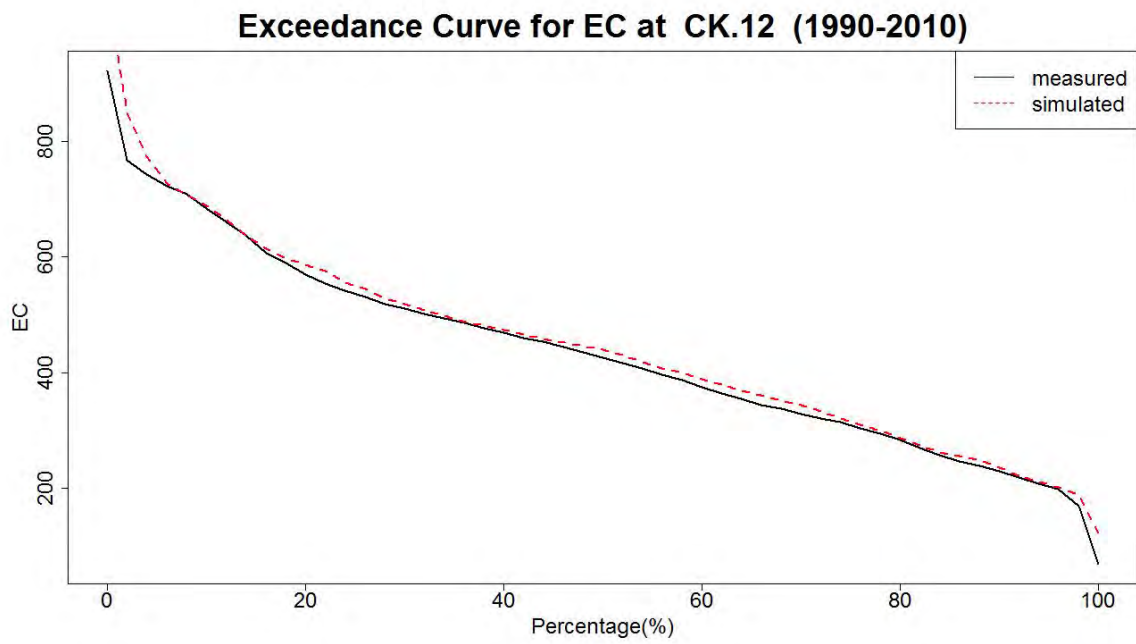


Figure 4.47 Exceedance Curve for EC at California Aqueduct Check 13

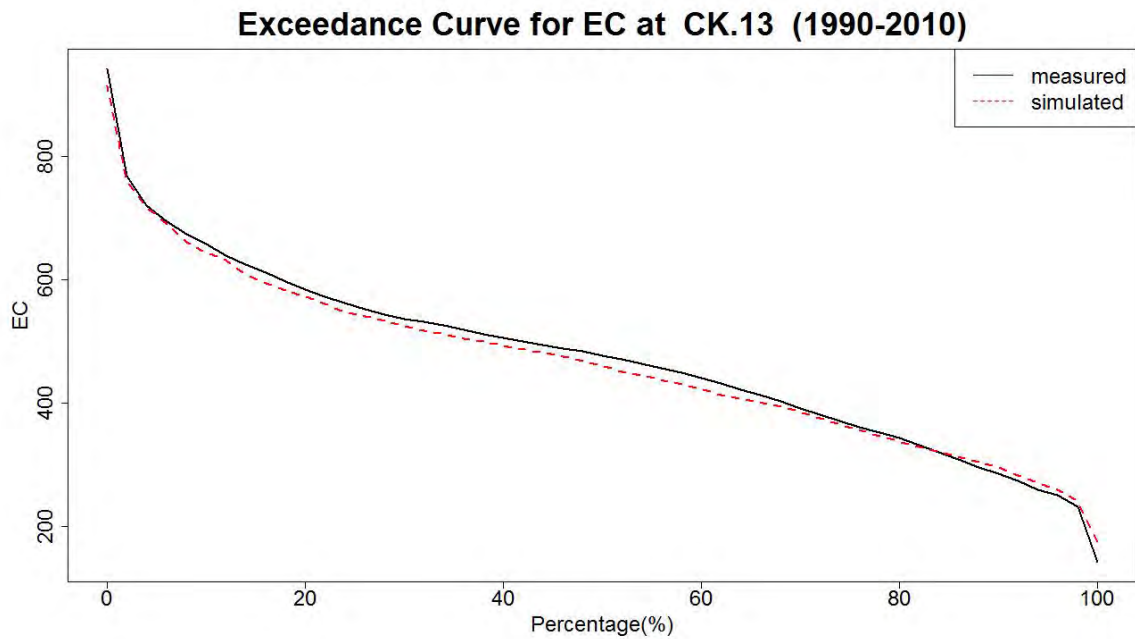


Figure 4.48 Exceedance Curve for EC at California Aqueduct Check 18

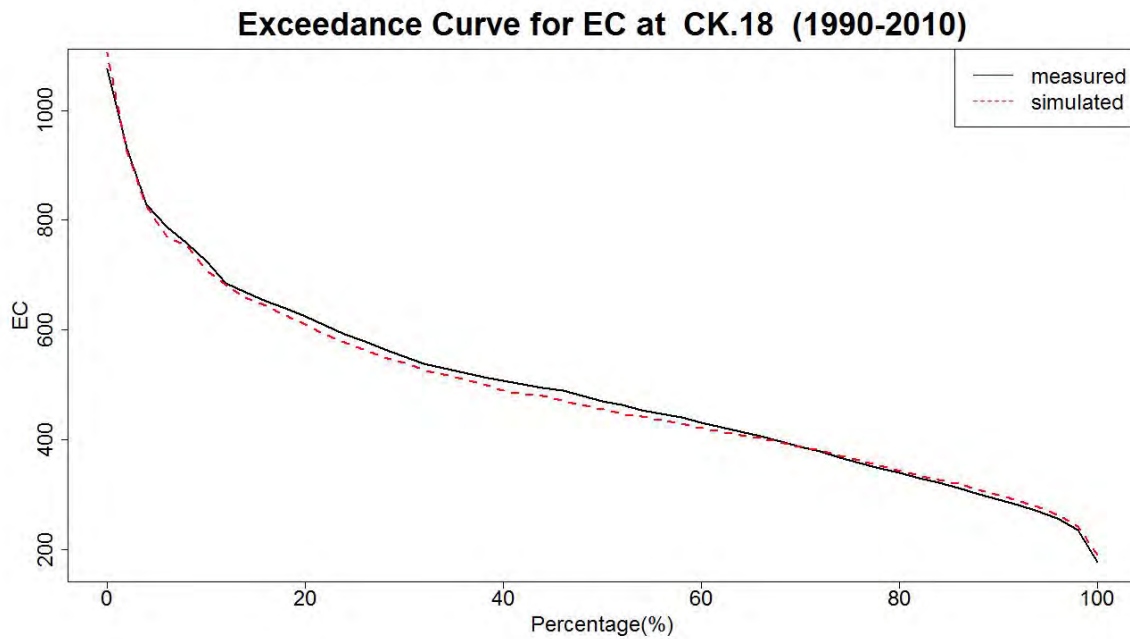


Figure 4.49 Exceedance Curve for EC at California Aqueduct Check21

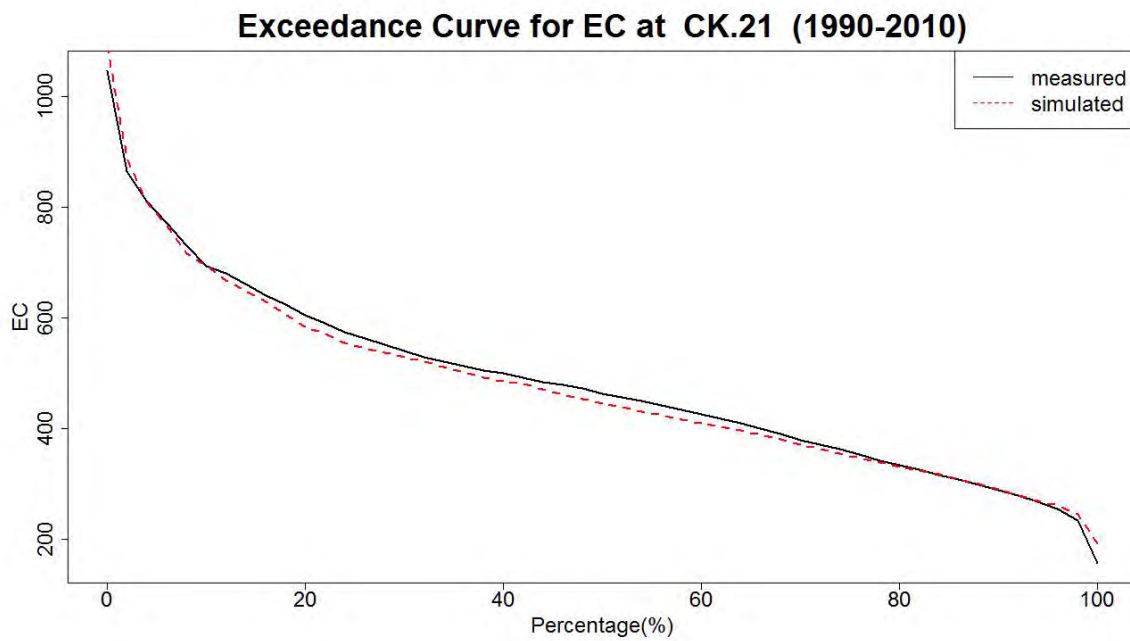


Figure 4.50 Exceedance Curve for EC at California Aqueduct Check 29

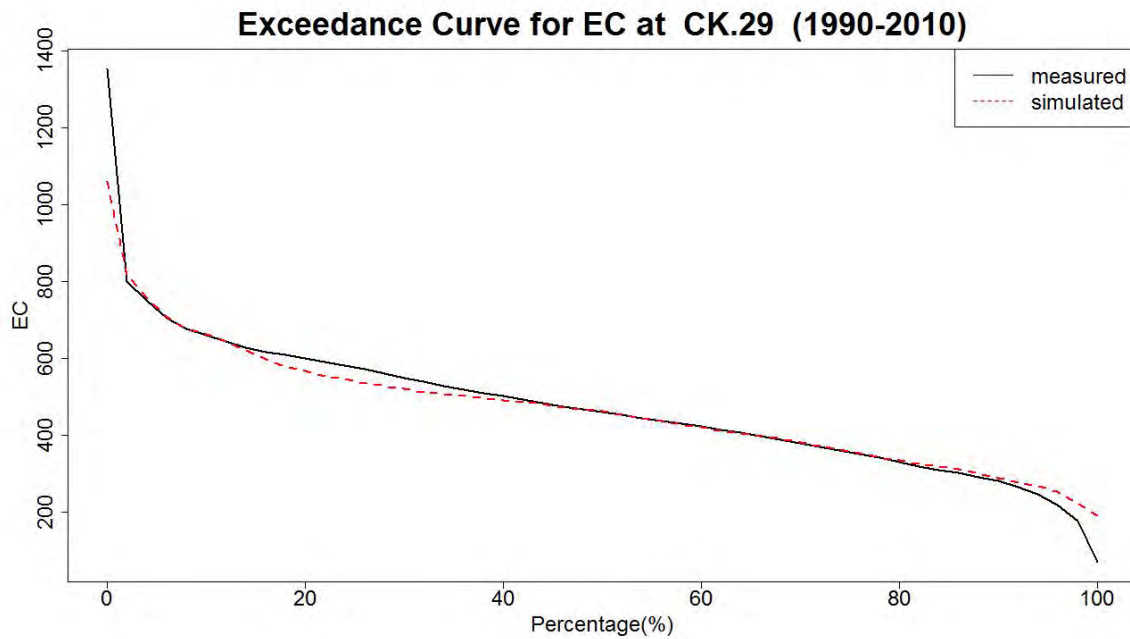


Figure 4.51 Exceedance Curve for EC at California Aqueduct Check 41

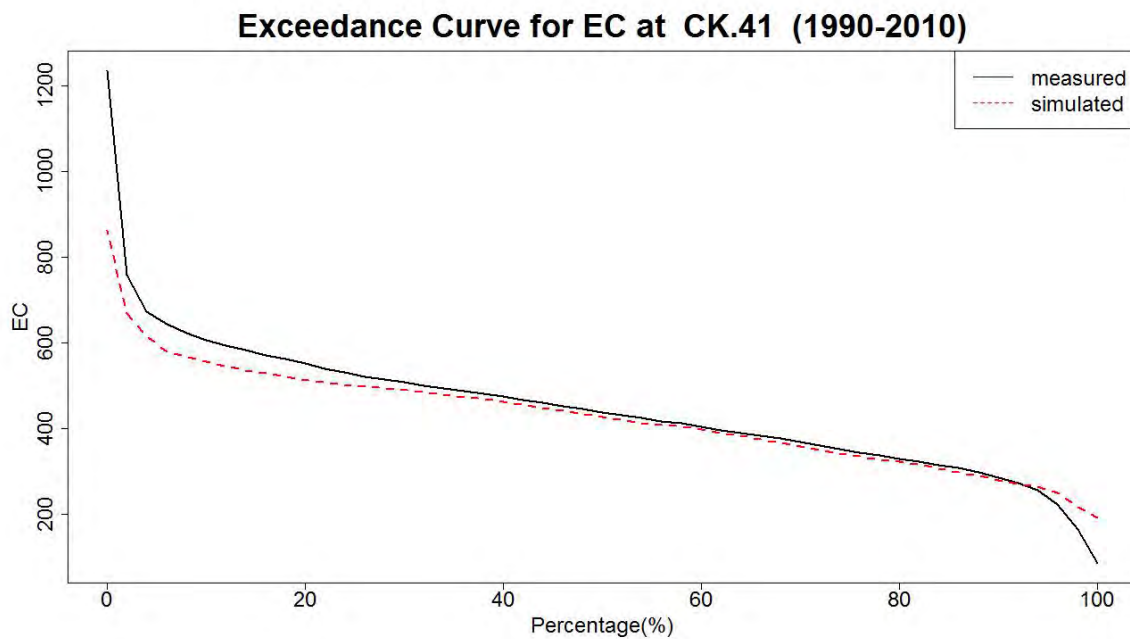


Figure 4.52 Exceedance Curve for EC at California Aqueduct Check 66

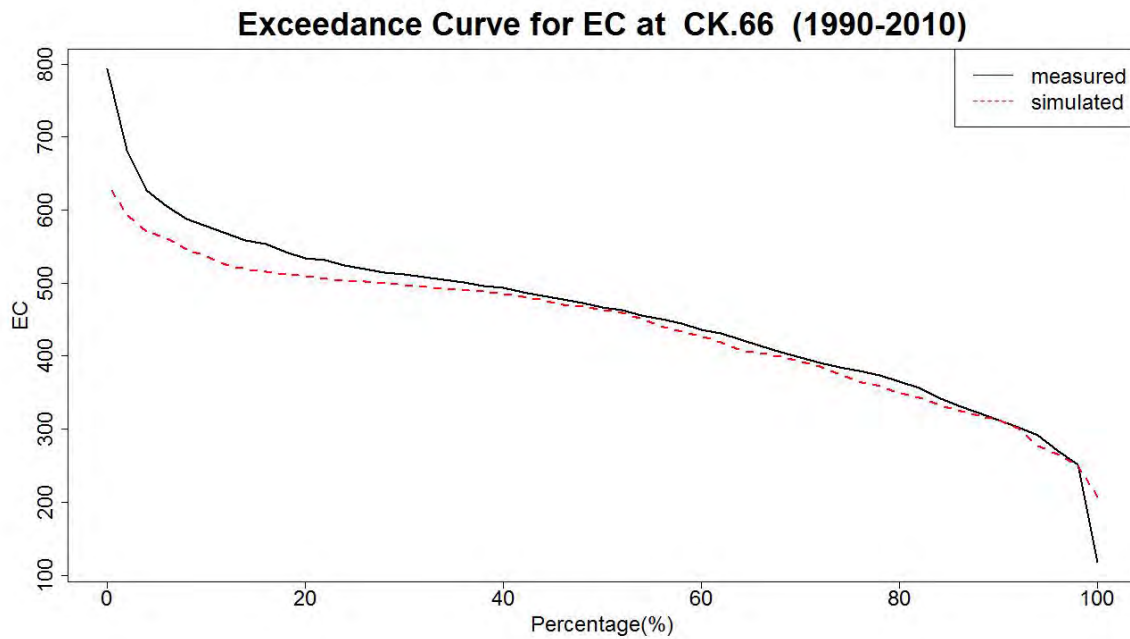


Figure 4.53 Exceedance Curve for EC at Del Valle Check 7, South Bay Aqueduct

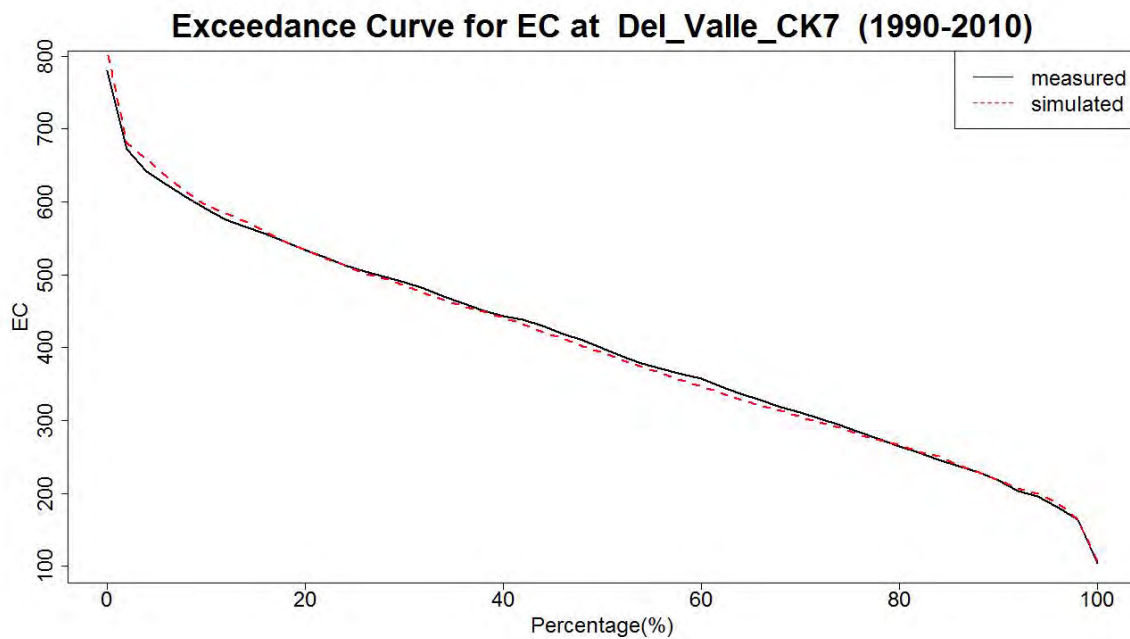


Figure 4.54 Exceedance Curve for EC at DMC Check 13

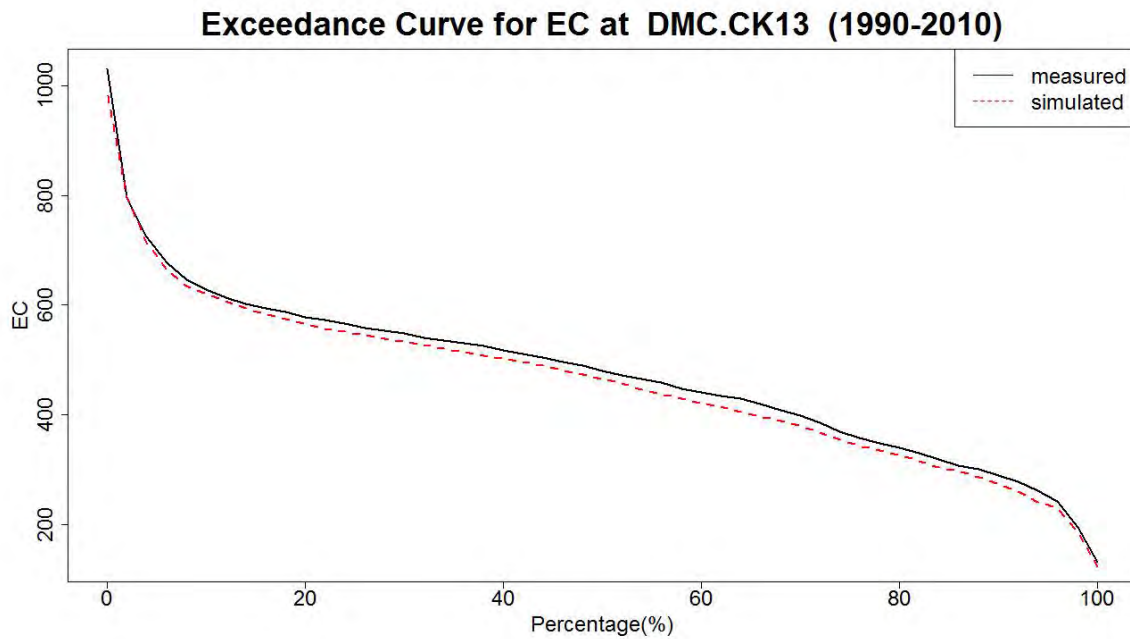


Figure 4.55 Exceedance Curve for EC at DMC Check 20

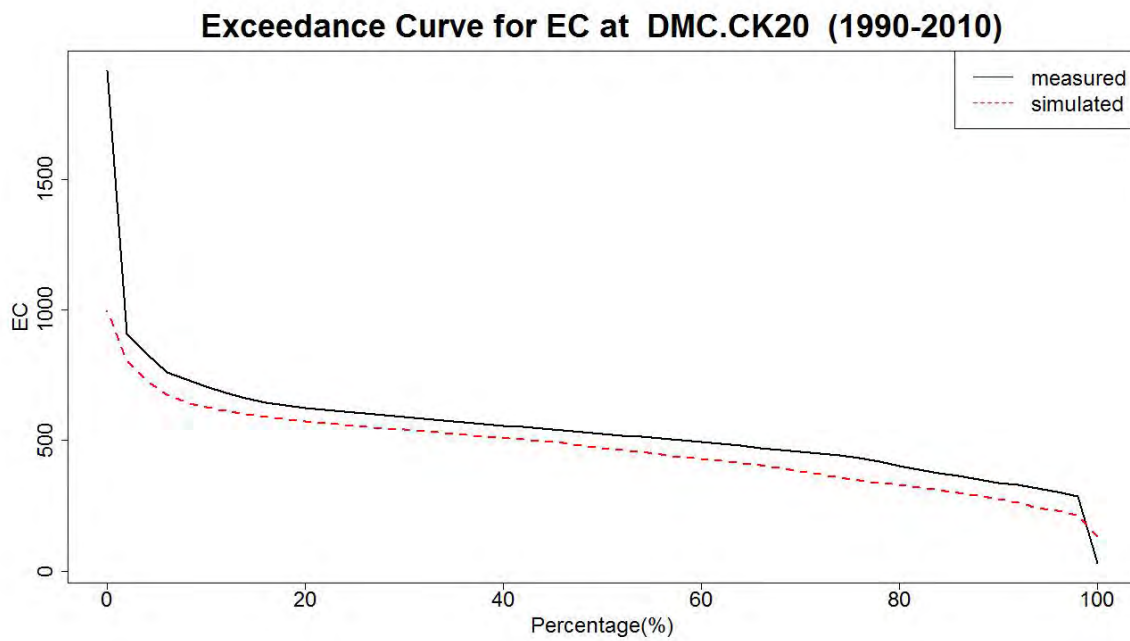


Figure 4.56 Exceedance Curve for EC at DMC Check 21

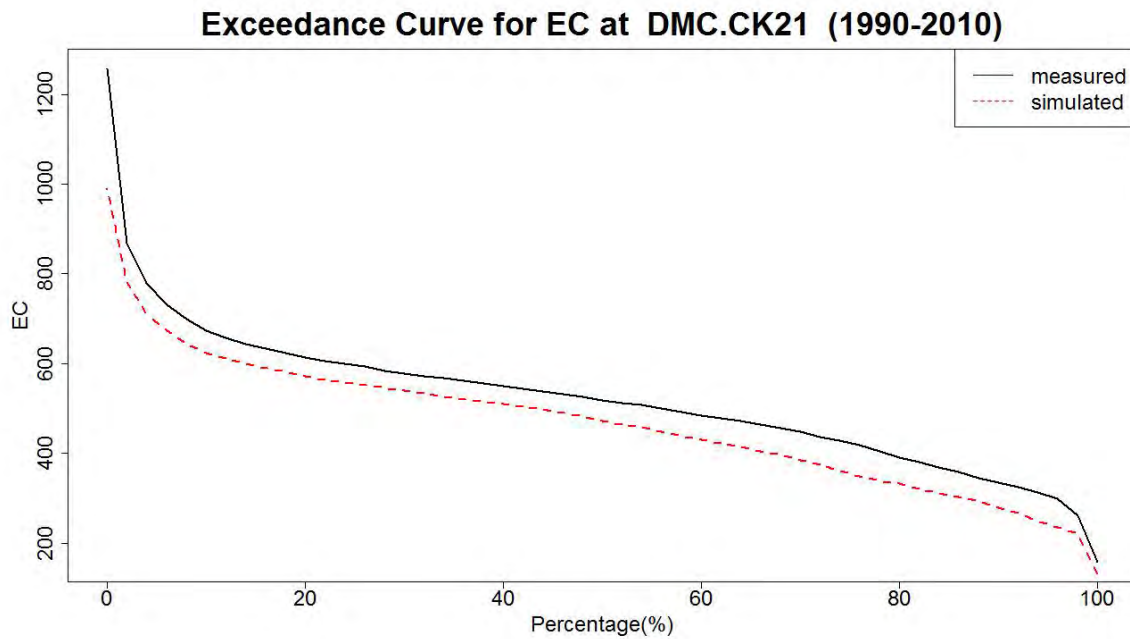


Figure 4.57 Exceedance Curve for EC at San Luis Reservoir

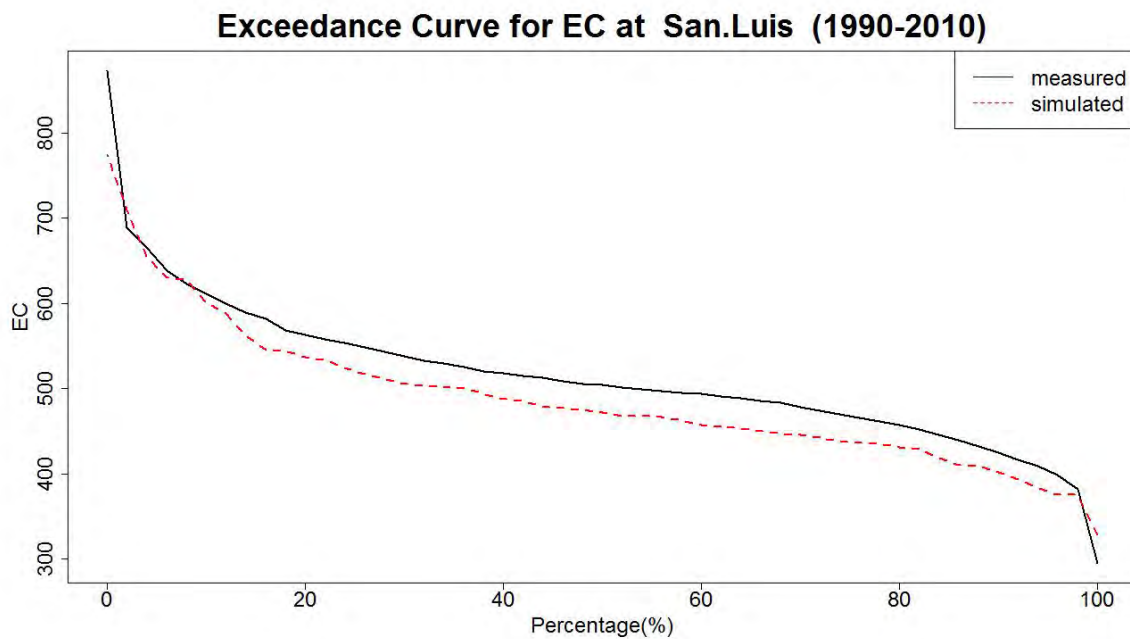


Figure 4.58 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 12

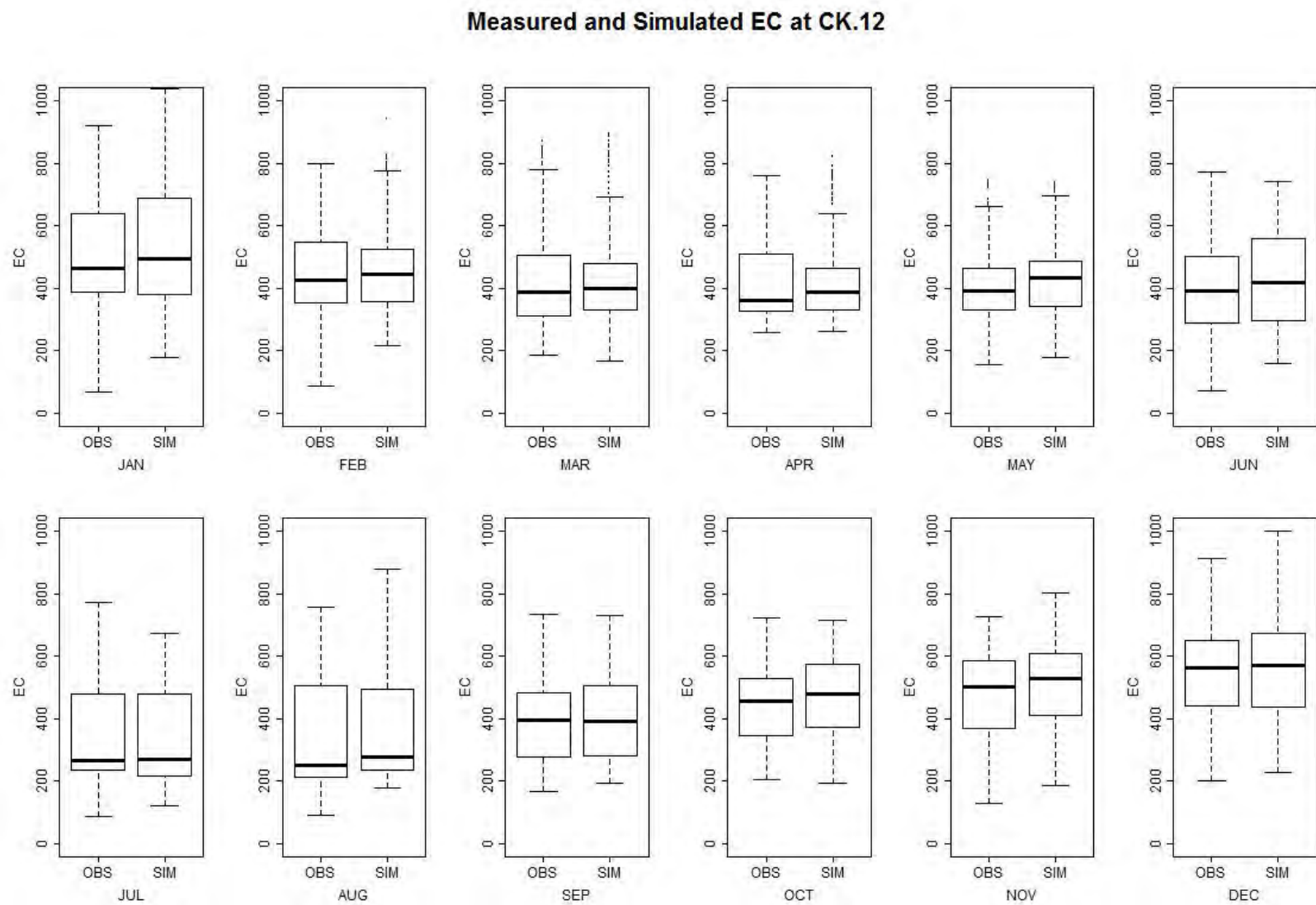


Figure 4.59 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 13

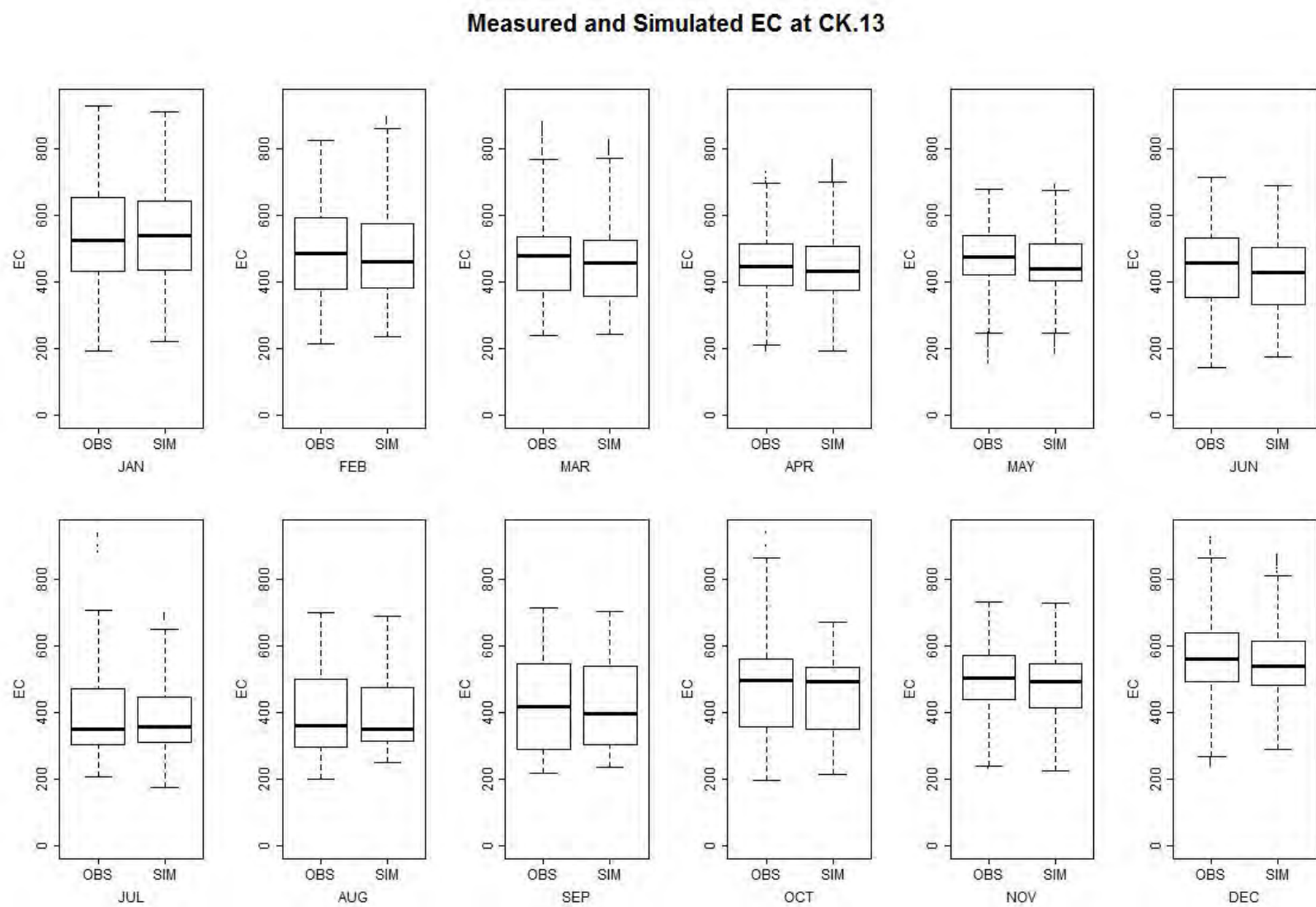


Figure 4.60 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 18

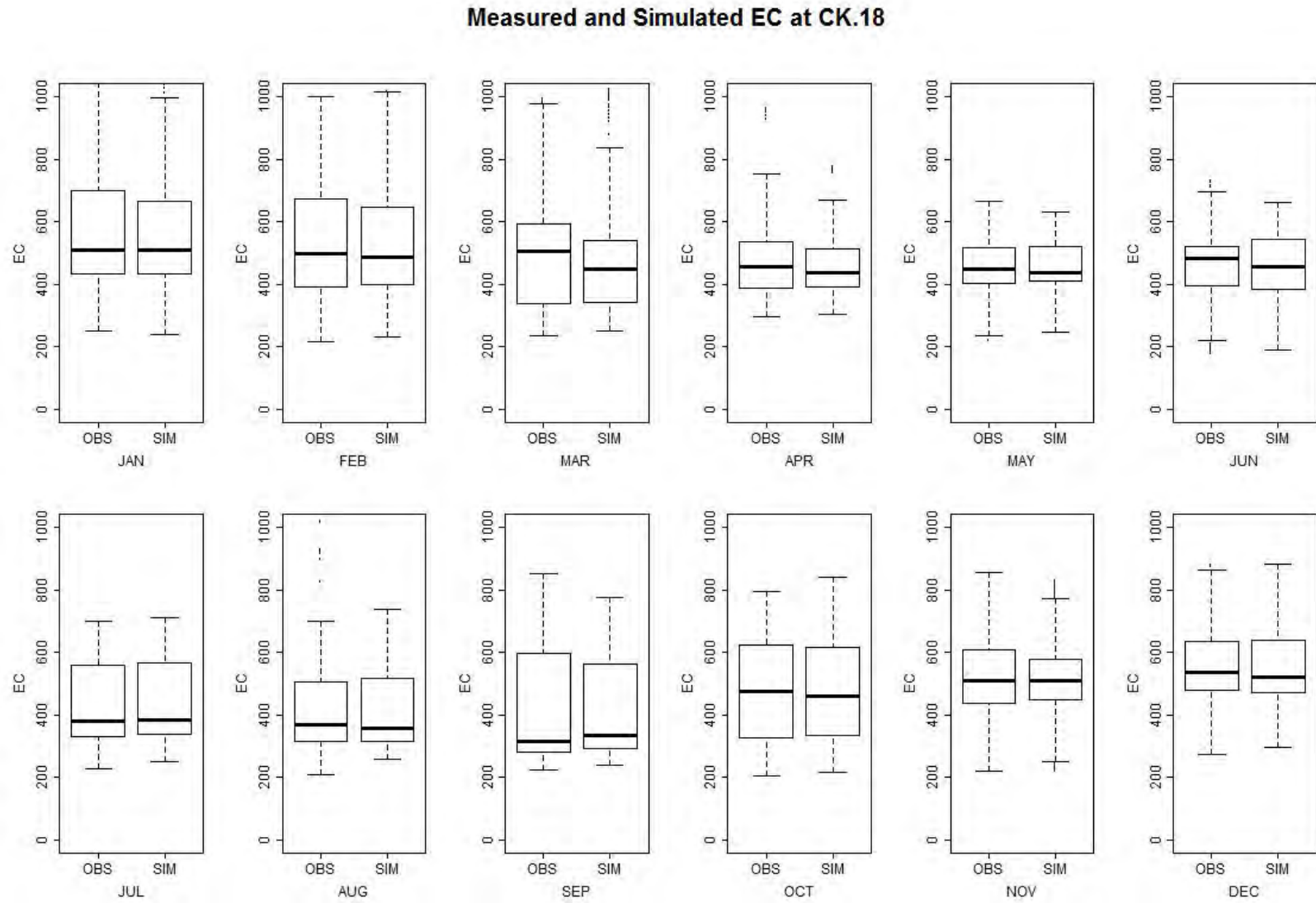


Figure 4.61 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 21

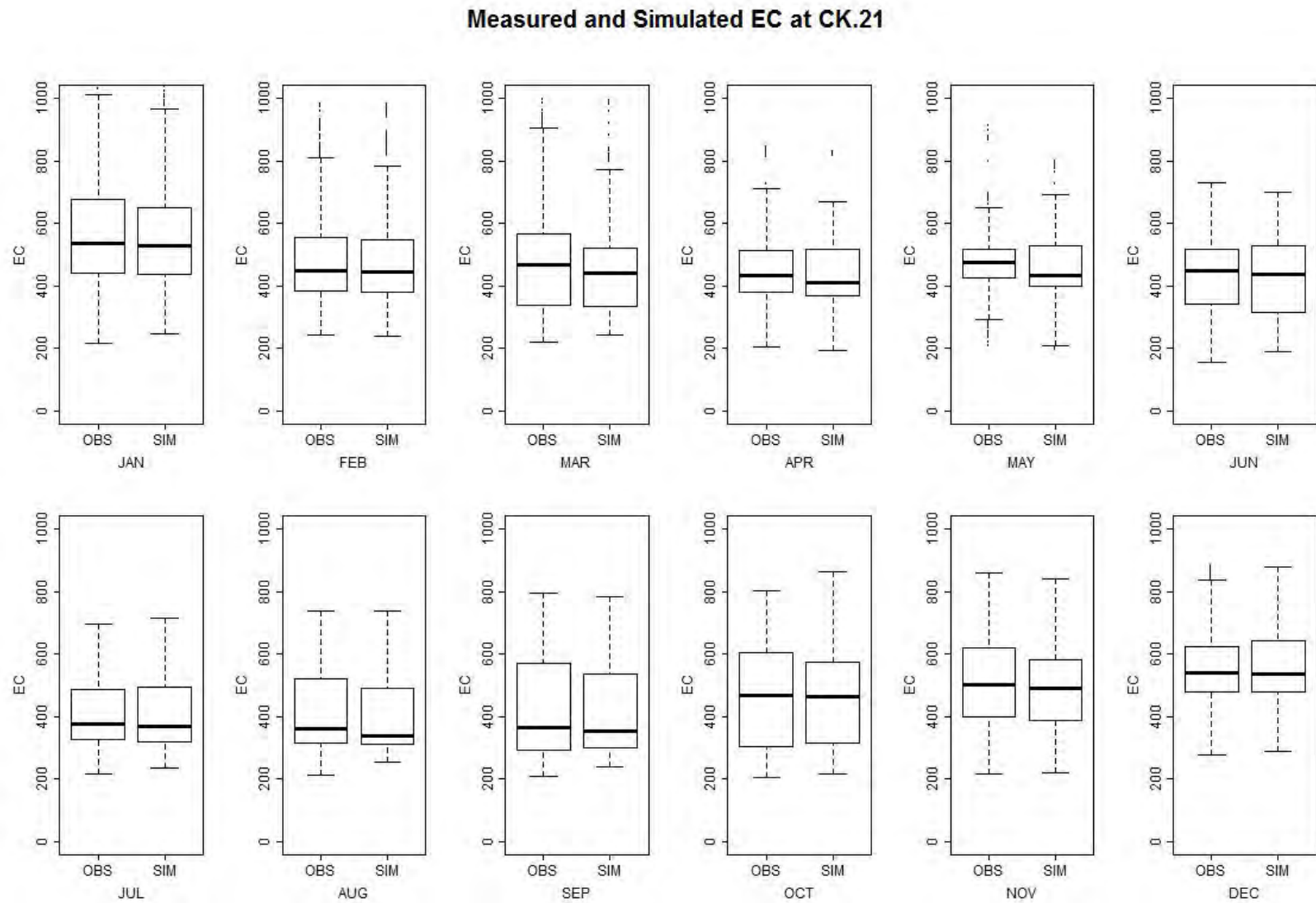


Figure 4.62 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 29

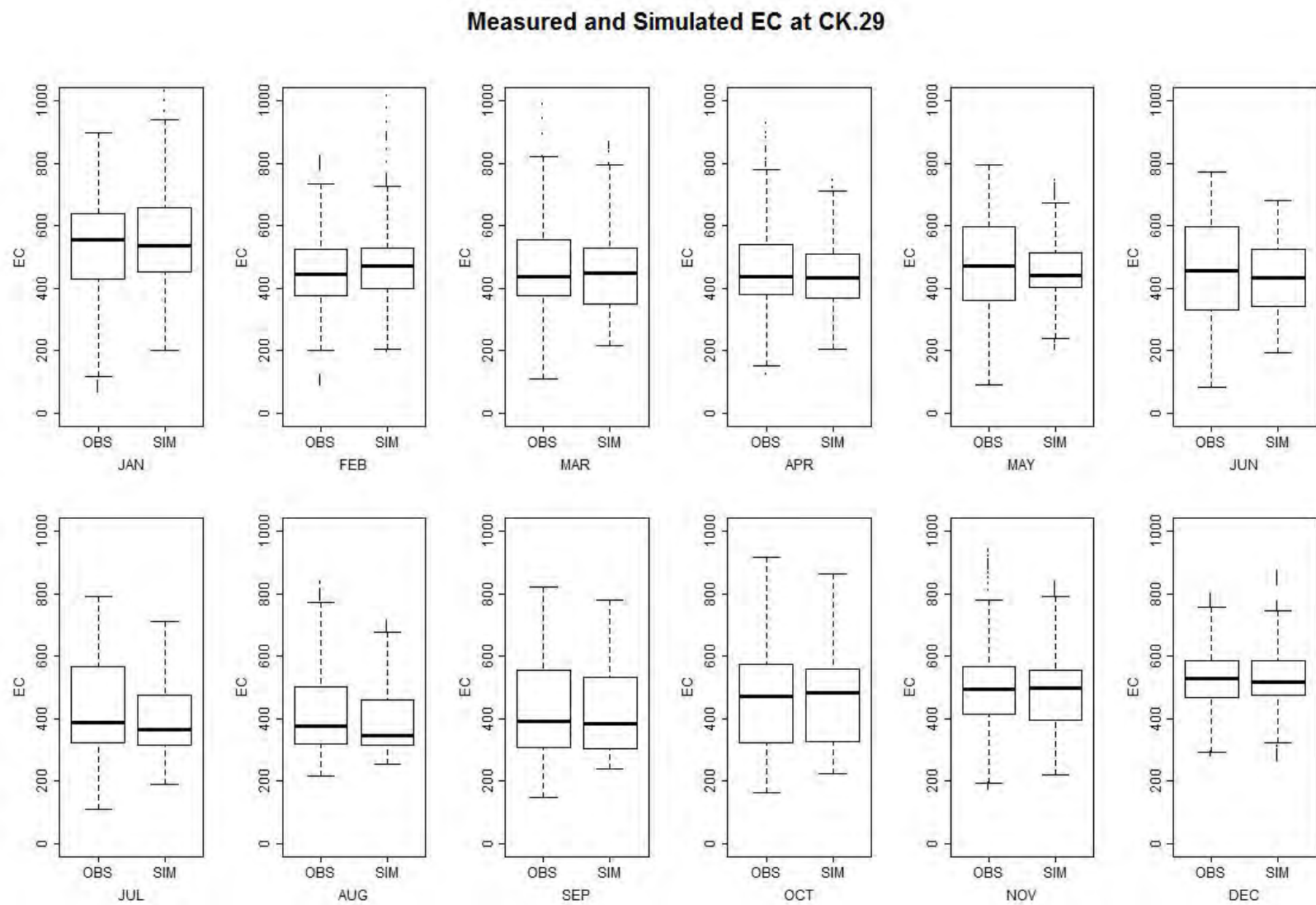


Figure 4.63 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 41

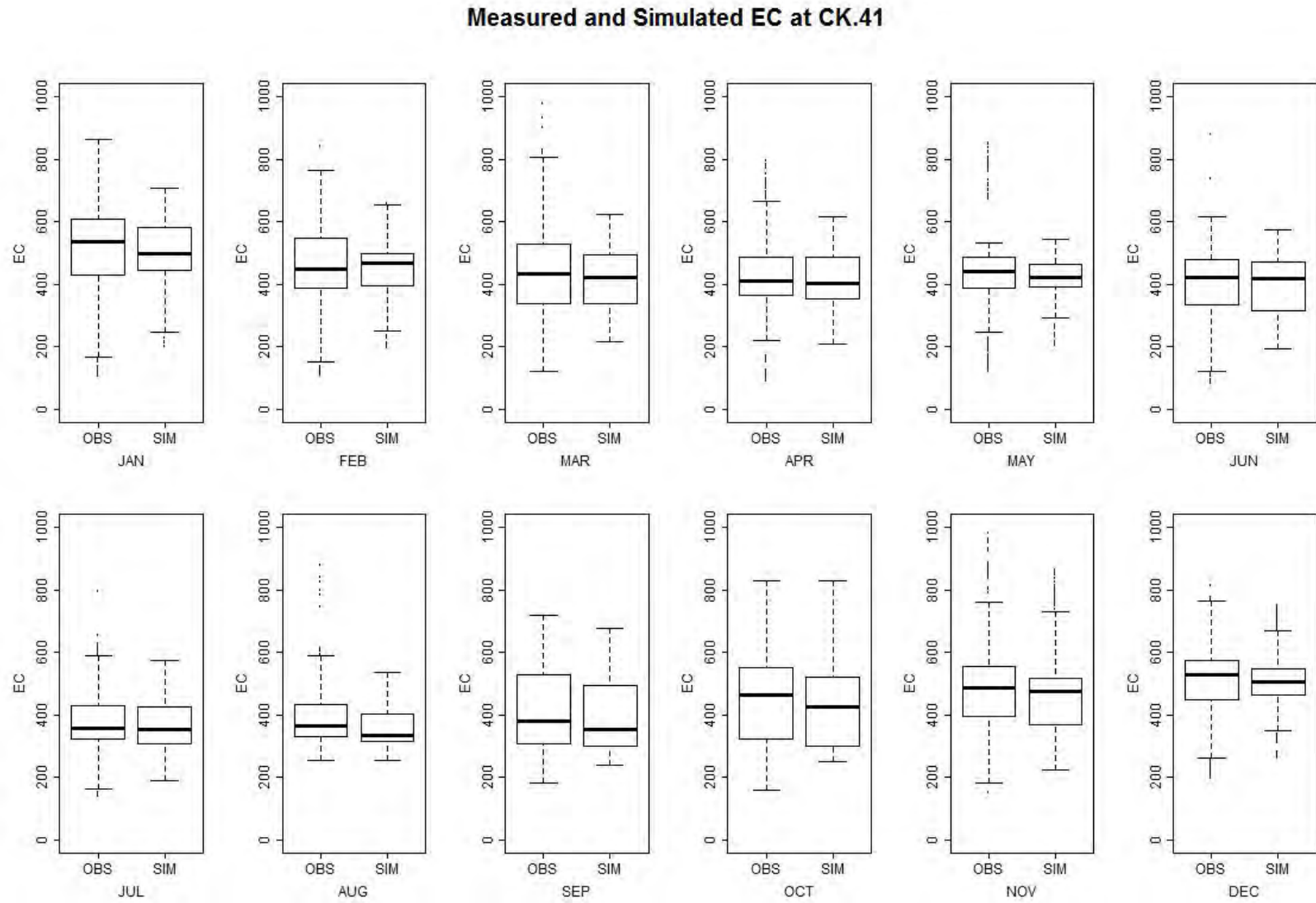


Figure 4.64 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 66

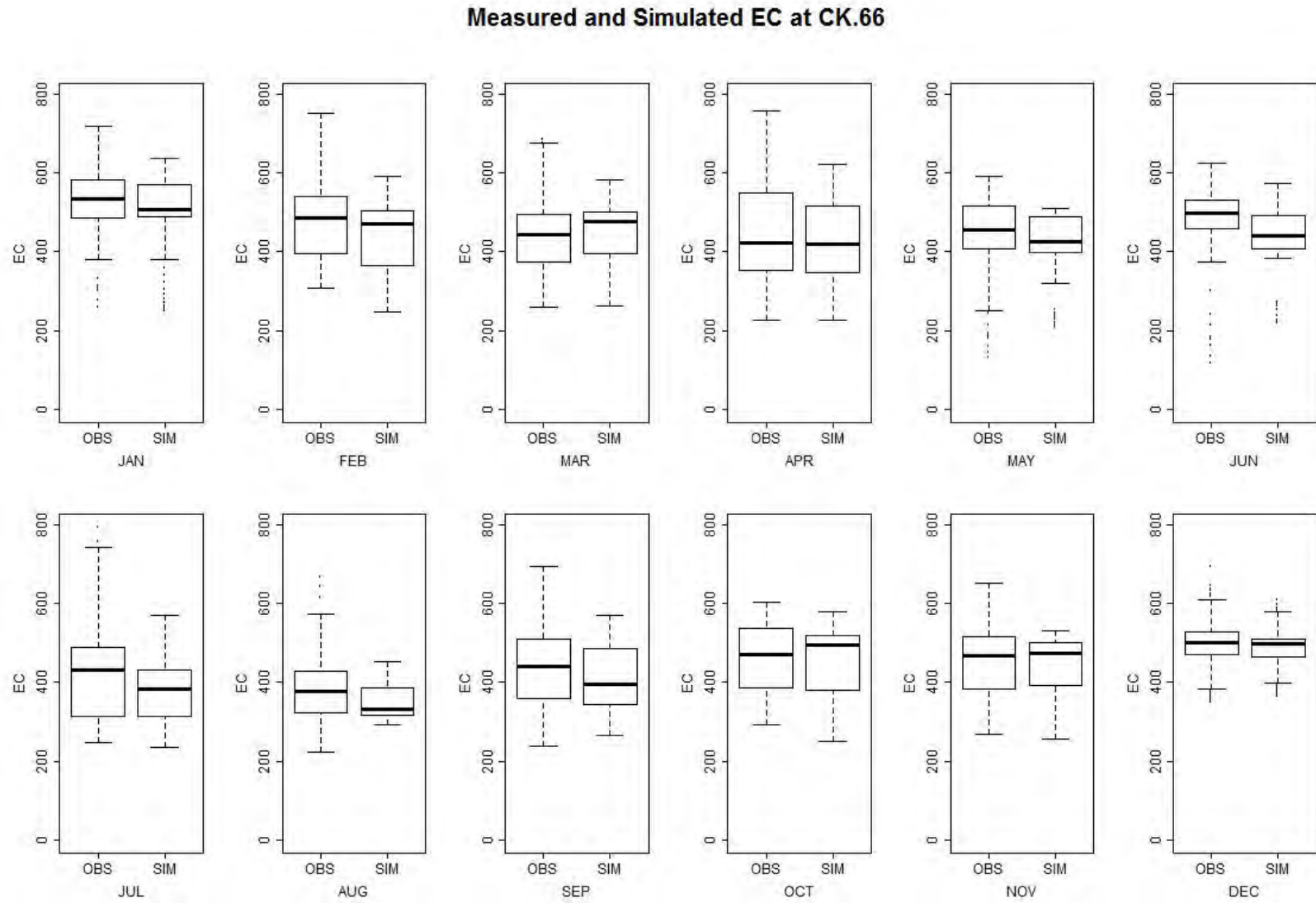


Figure 4.65 Month by Month Comparison of Measured and Simulated EC at Del Valle Check 7, South Bay Aqueduct

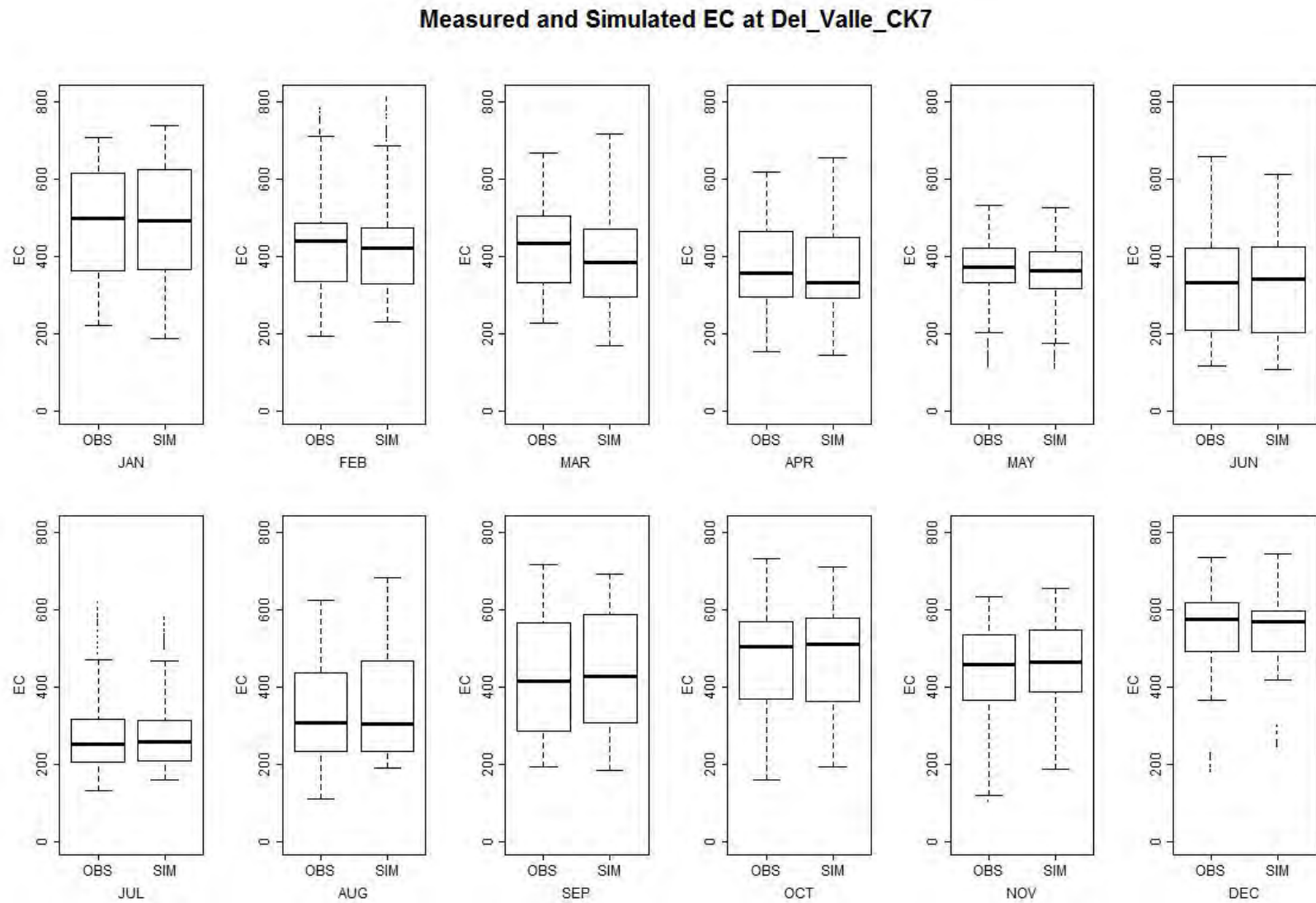


Figure 4.66 Month by Month Comparison of Measured and Simulated EC at DMC Check 13

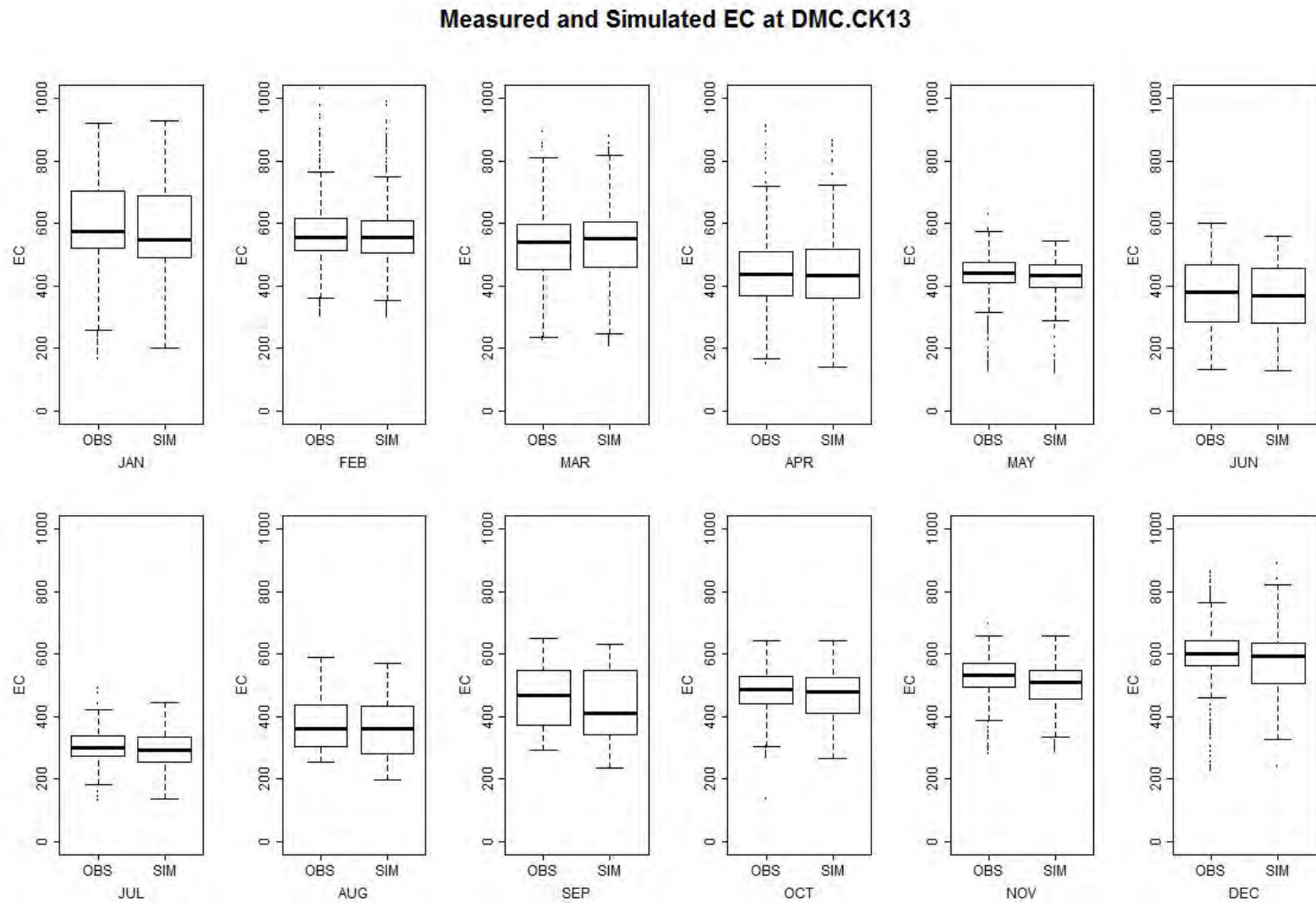


Figure 4.67 Month by Month Comparison of Measured and Simulated EC at DMC Check 20

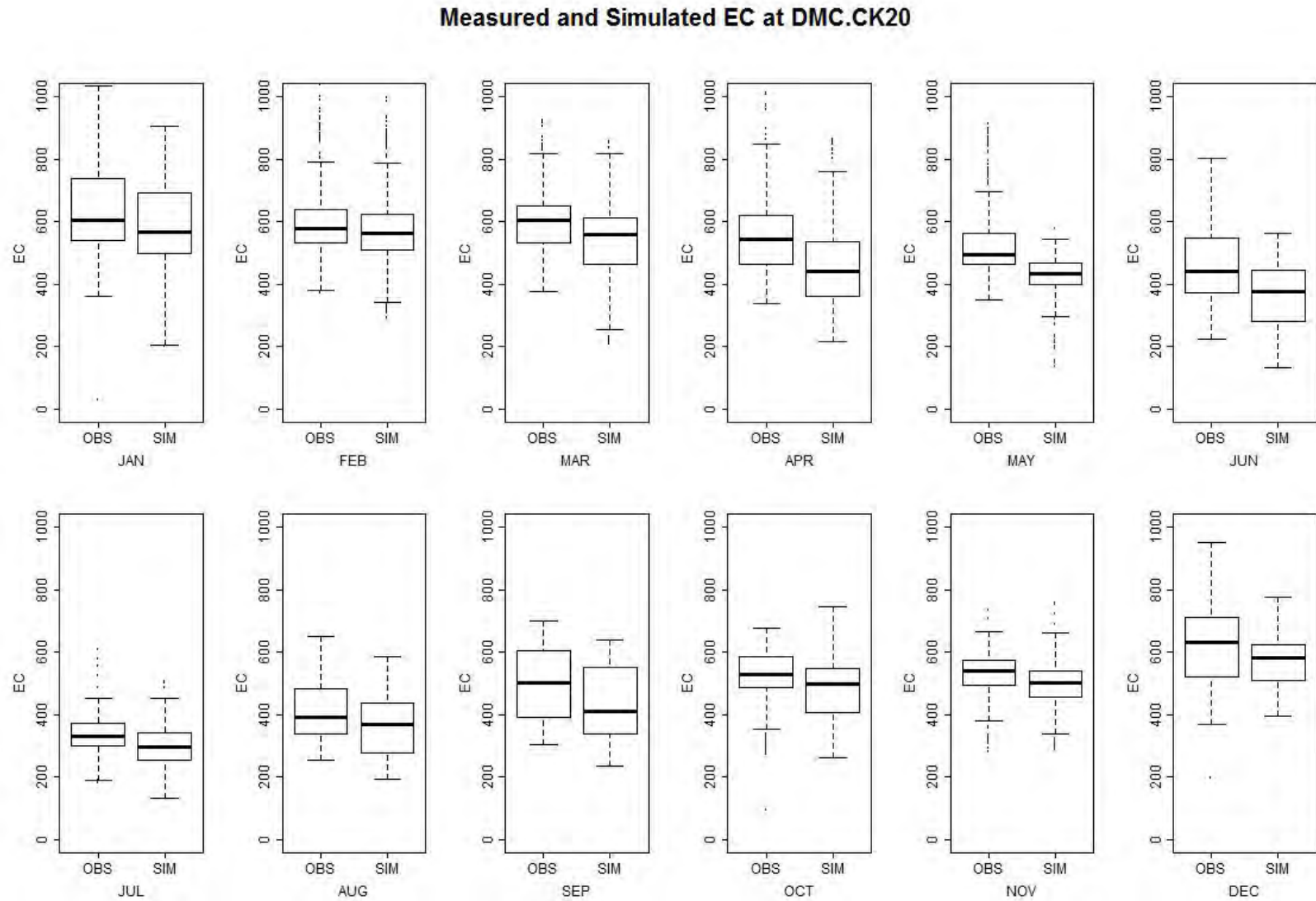


Figure 4.68 Month by Month Comparison of Measured and Simulated EC at DMC Check 21

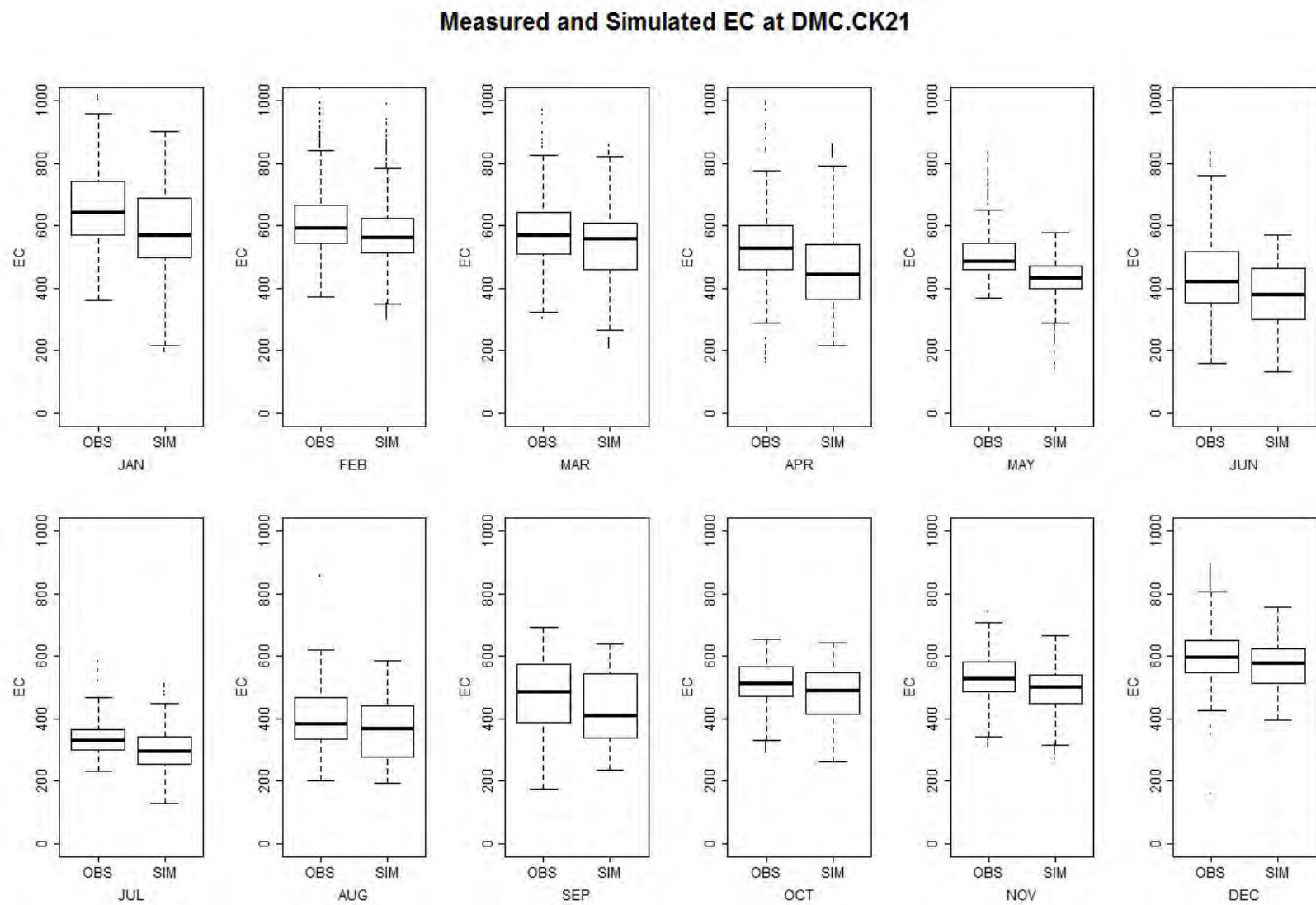


Figure 4.69 Month by Month Comparison of Measured and Simulated EC at San Luis Reservoir

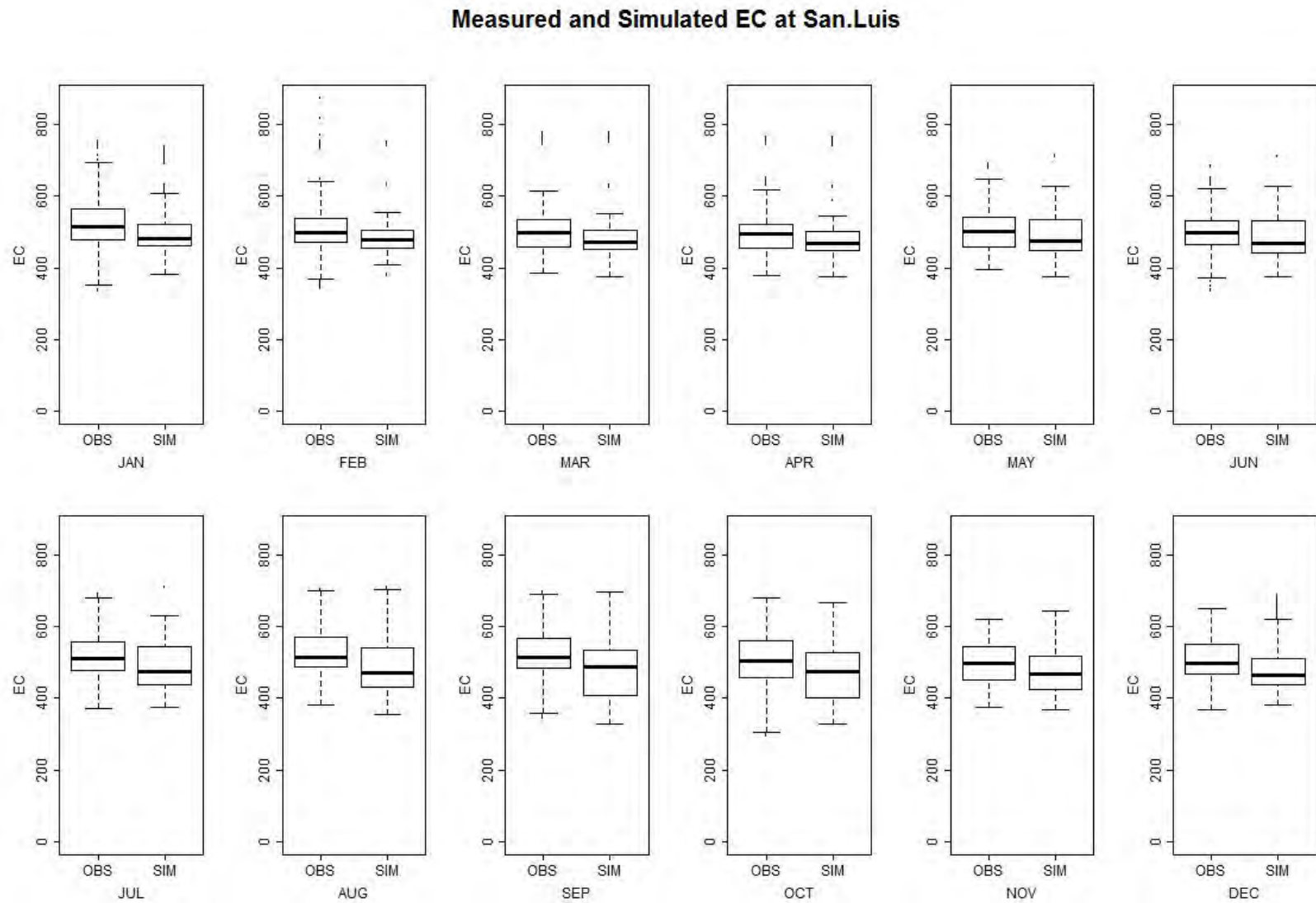


Figure 4.70 Comparison of Measured and Simulated Bromide at California Aqueduct Check 13

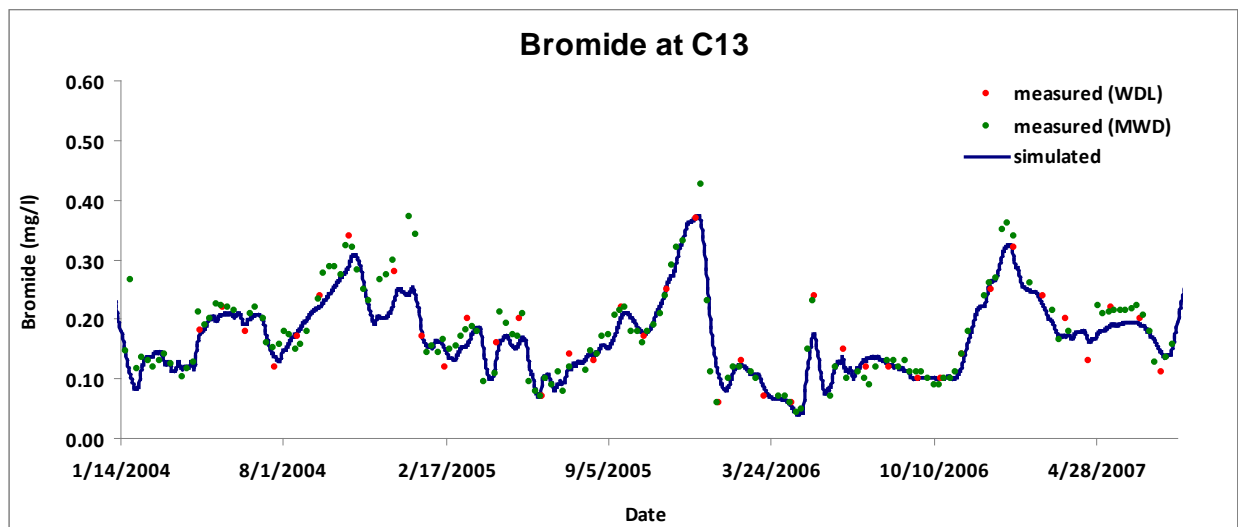
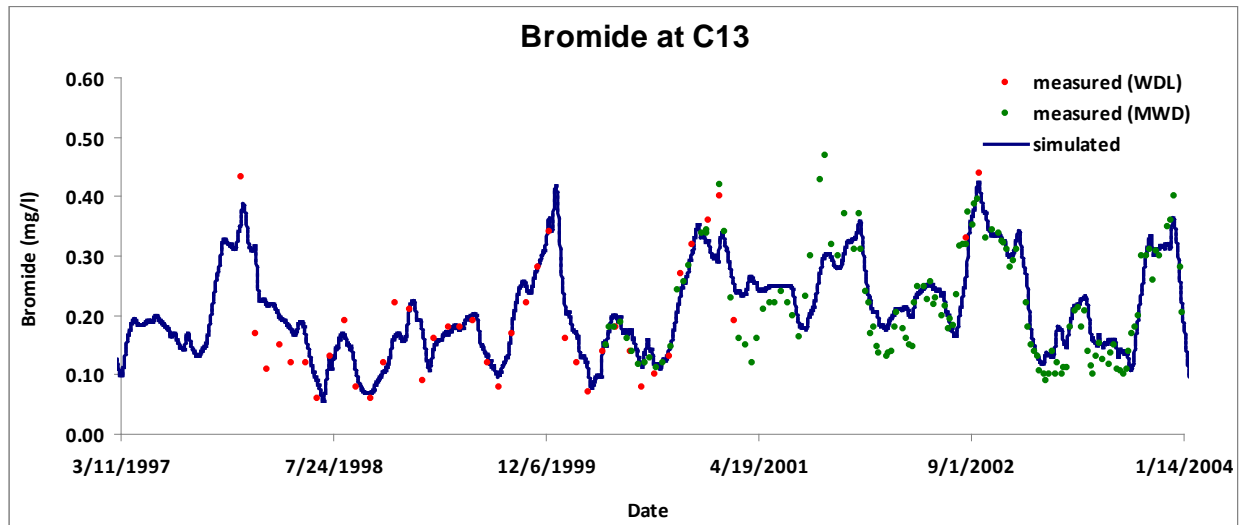


Figure 4.71 Comparison of Measured and Simulated Bromide at California Aqueduct Check 21

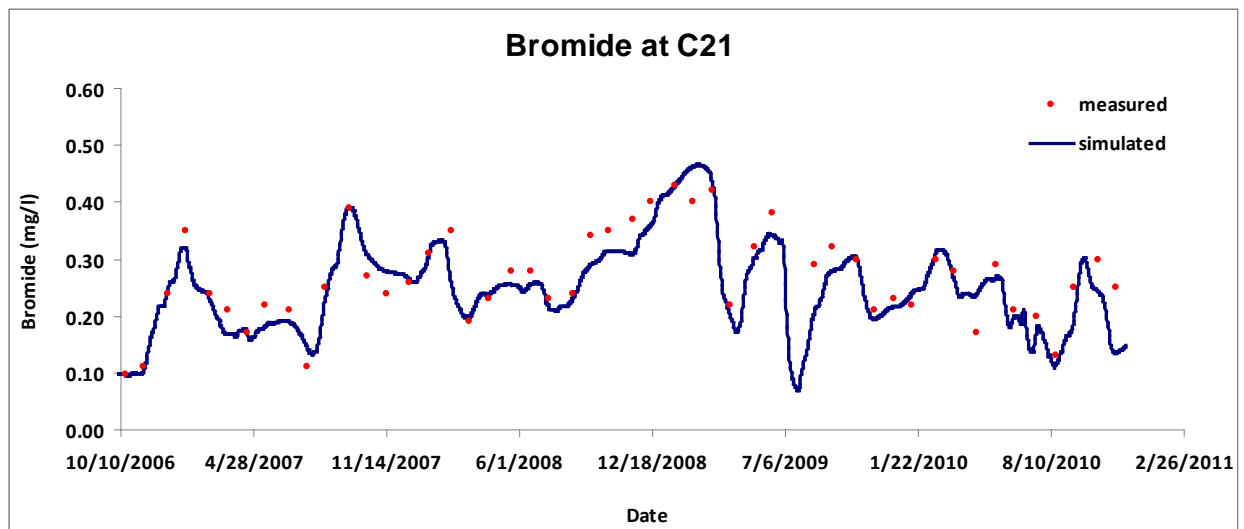
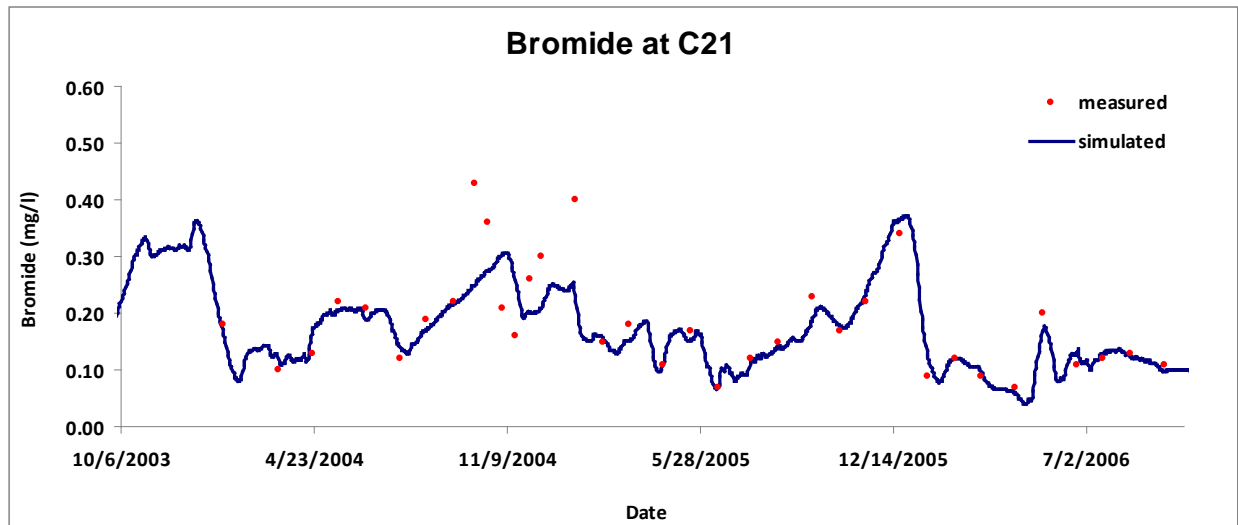


Figure 4.72 Comparison of Measured and Simulated Bromide at California Aqueduct Check 29

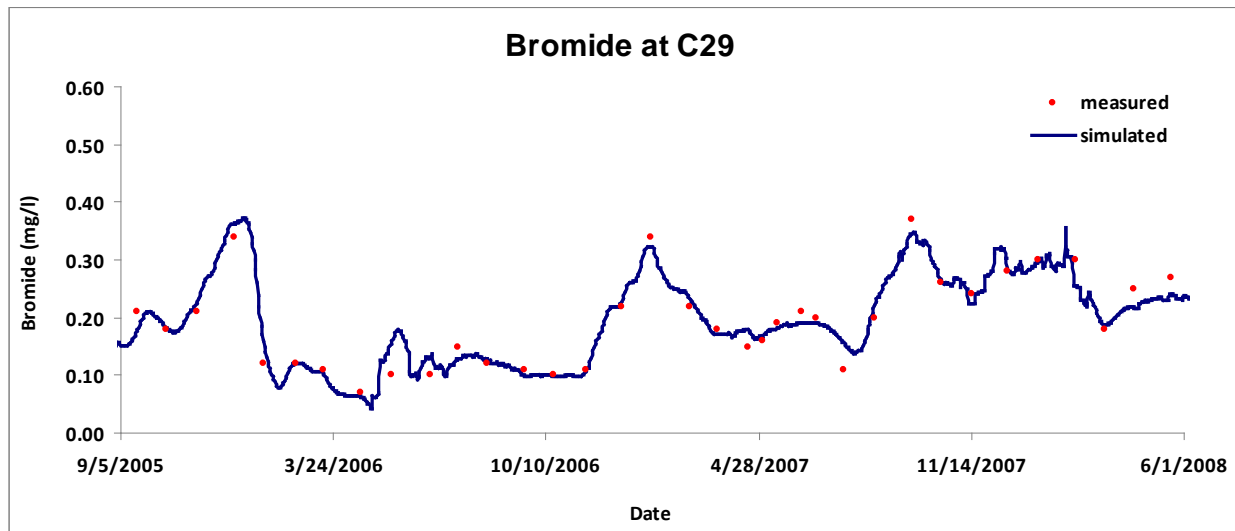
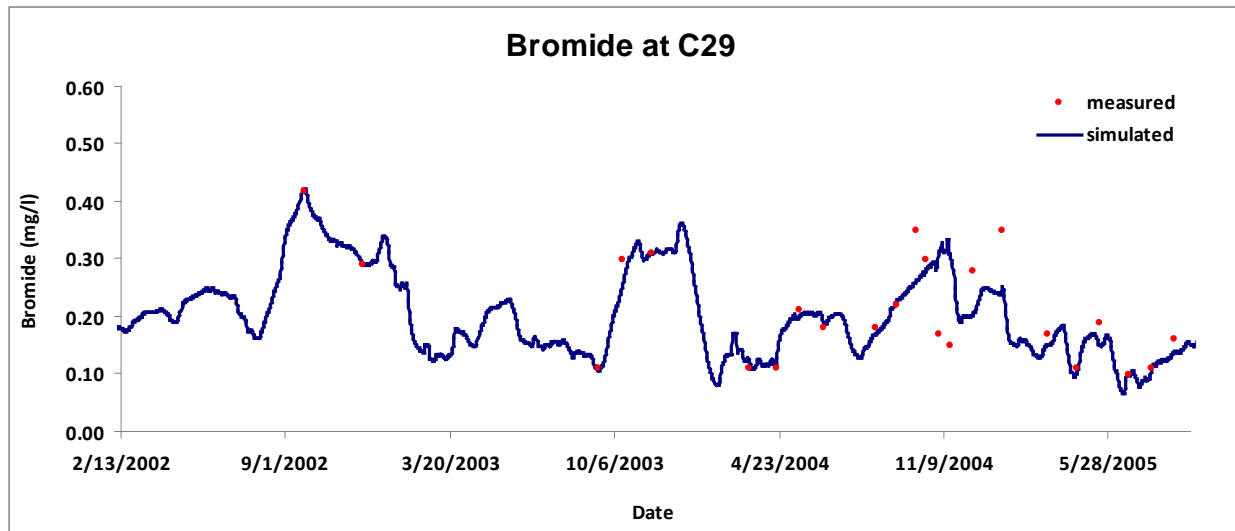


Figure 4.73 Comparison of Measured and Simulated Bromide at California Aqueduct Check 41

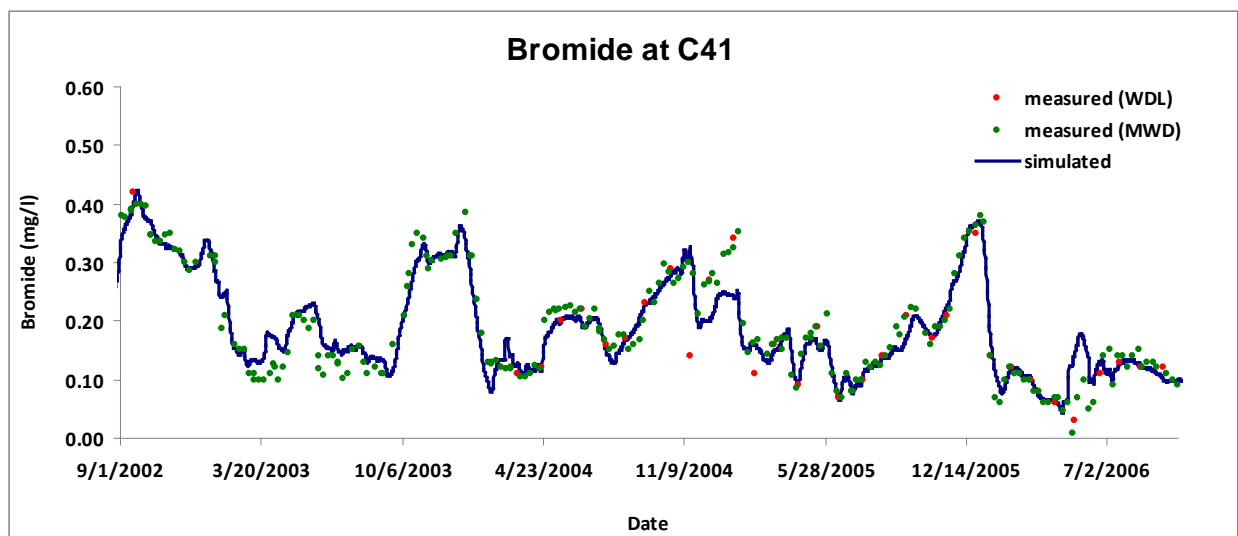
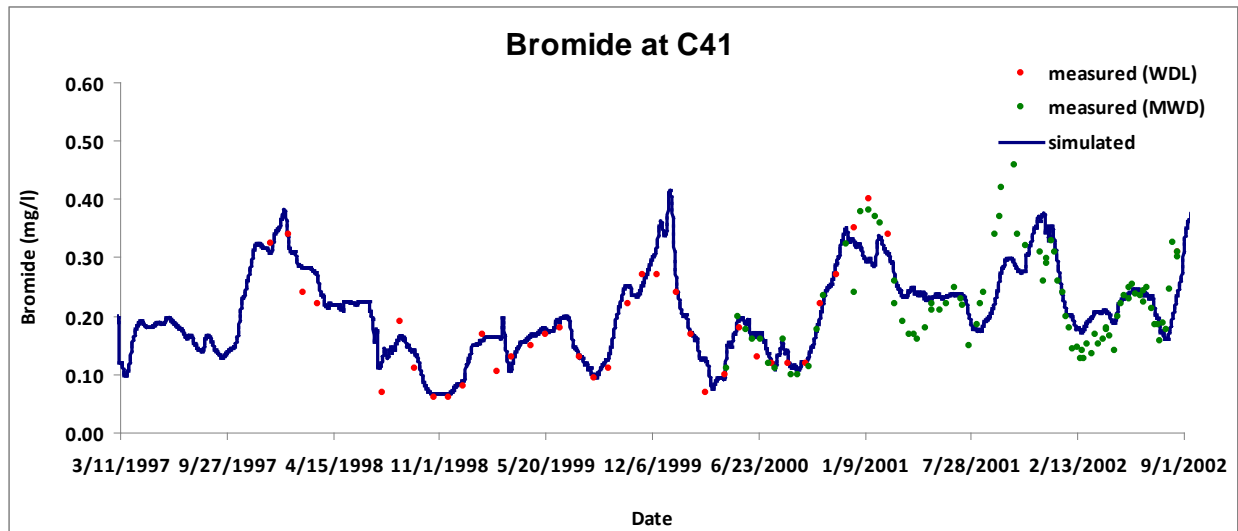


Figure 4.74 Comparison of Measured and Simulated Bromide at California Aqueduct Check 66

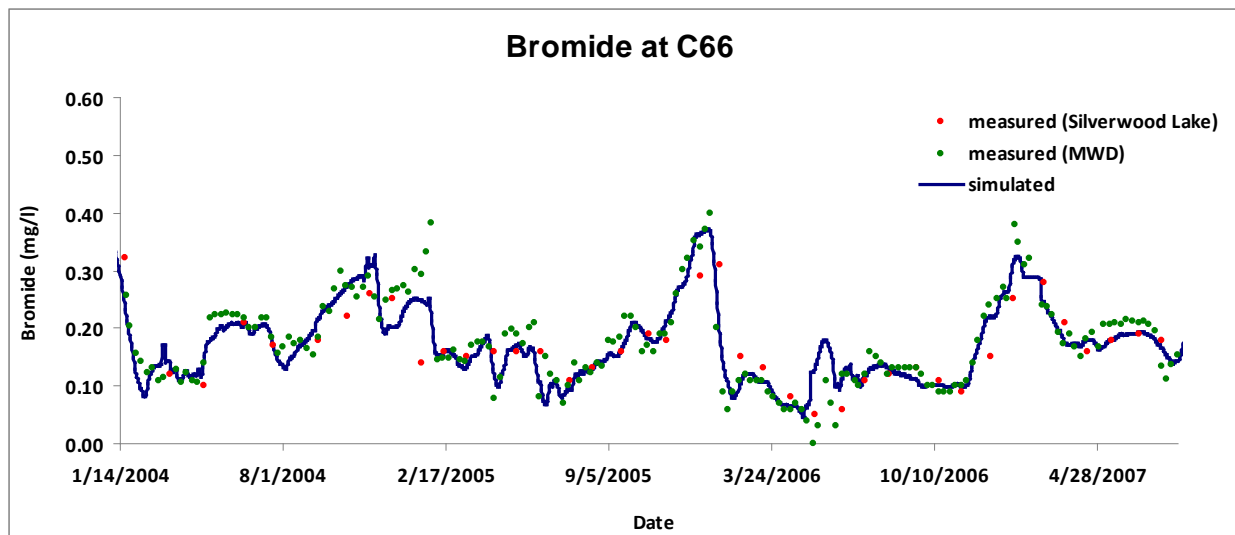
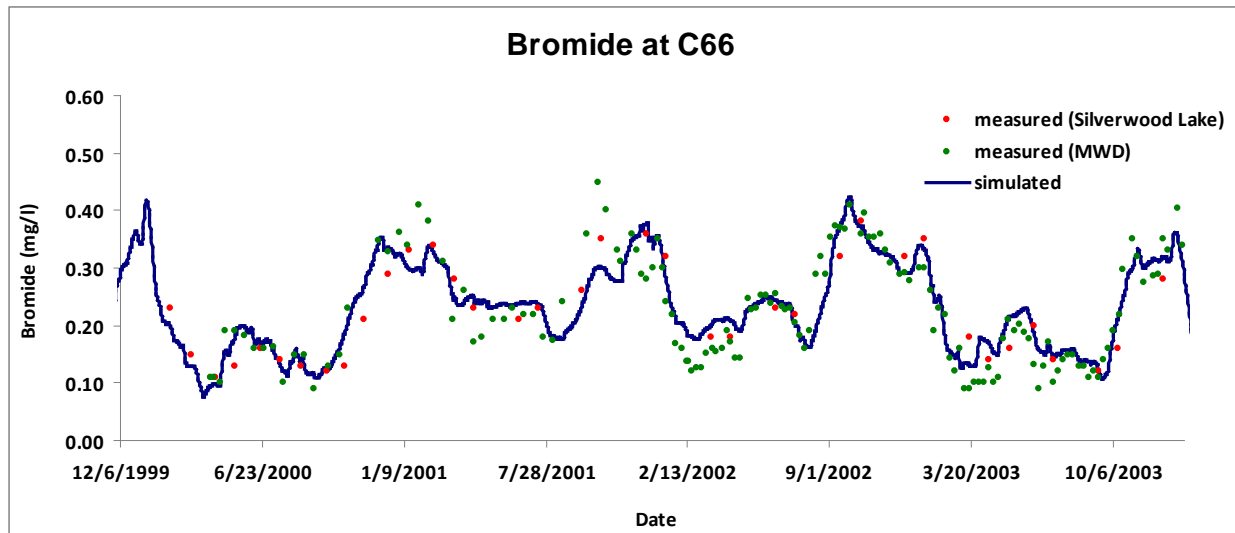


Figure 4.75 Comparison of Measured and Simulated Bromide at San Luis Reservoir

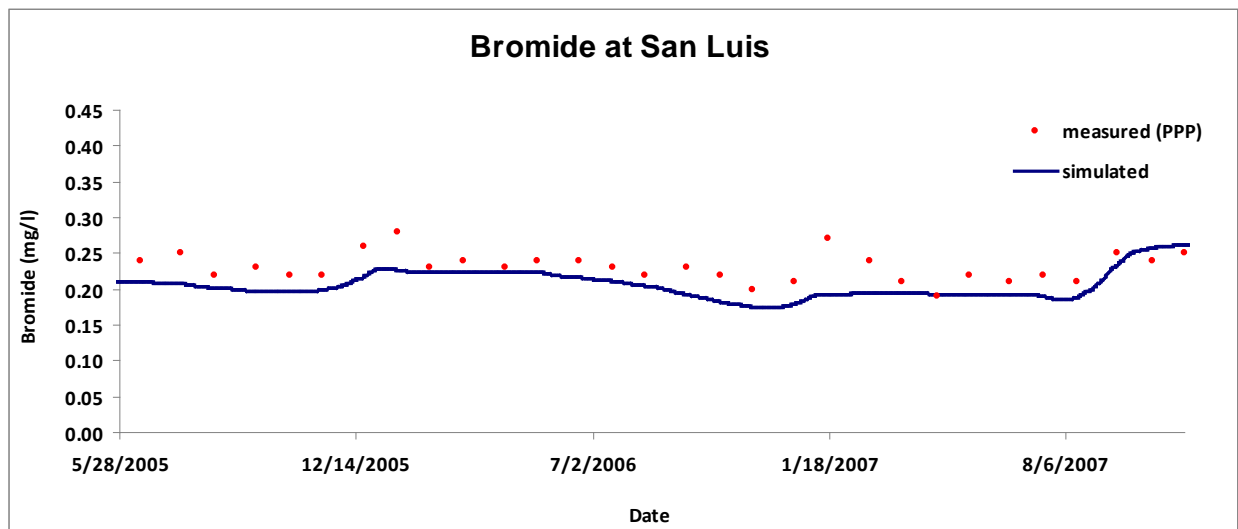
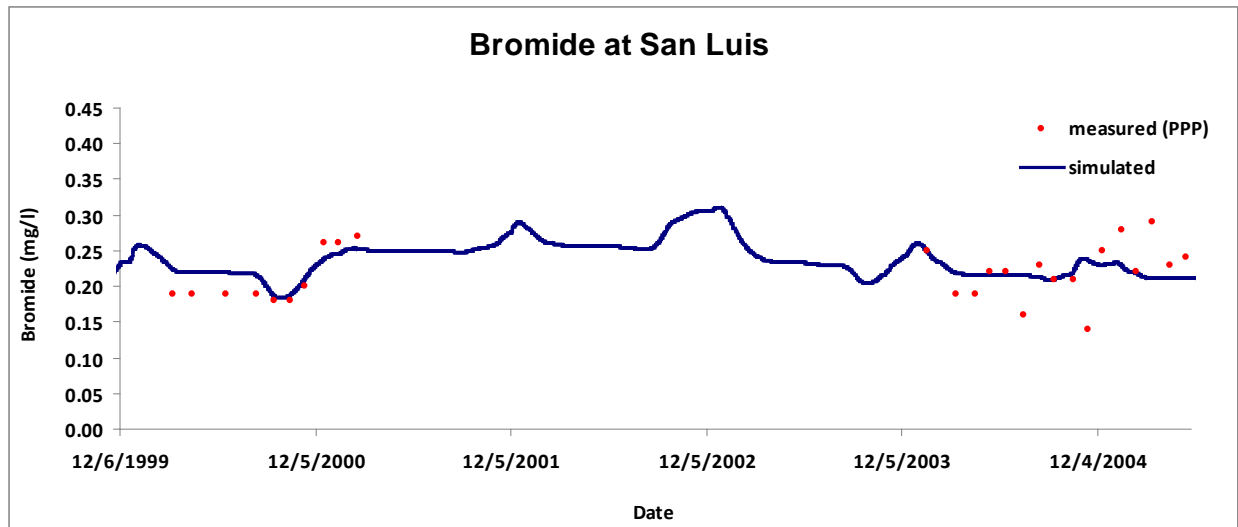


Figure 4.76 Comparison of Measured and Simulated Bromide at California Aqueduct Check 13

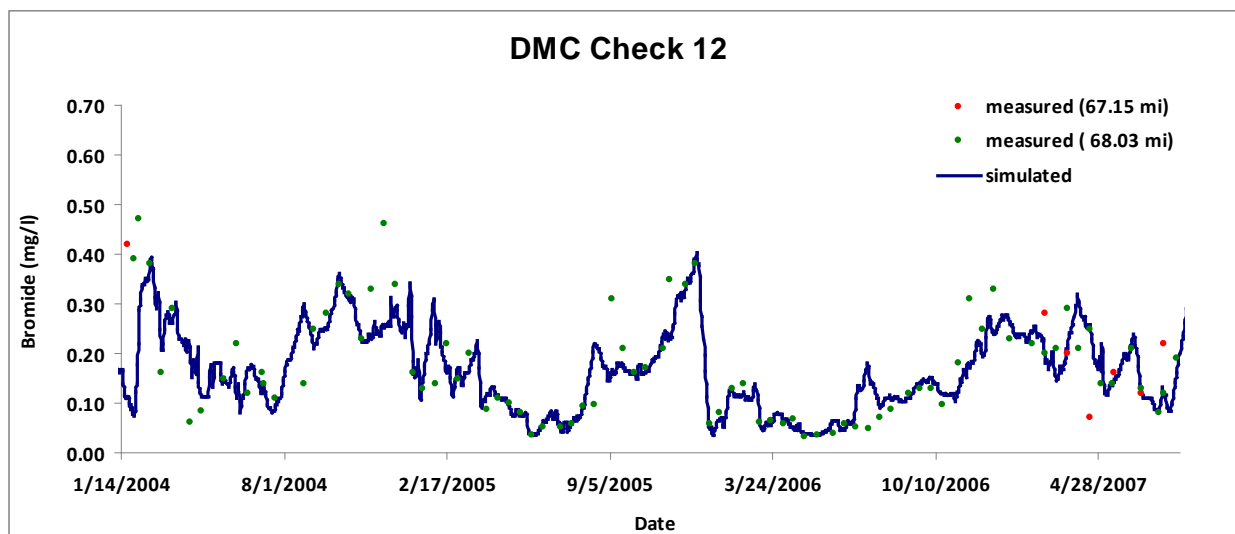
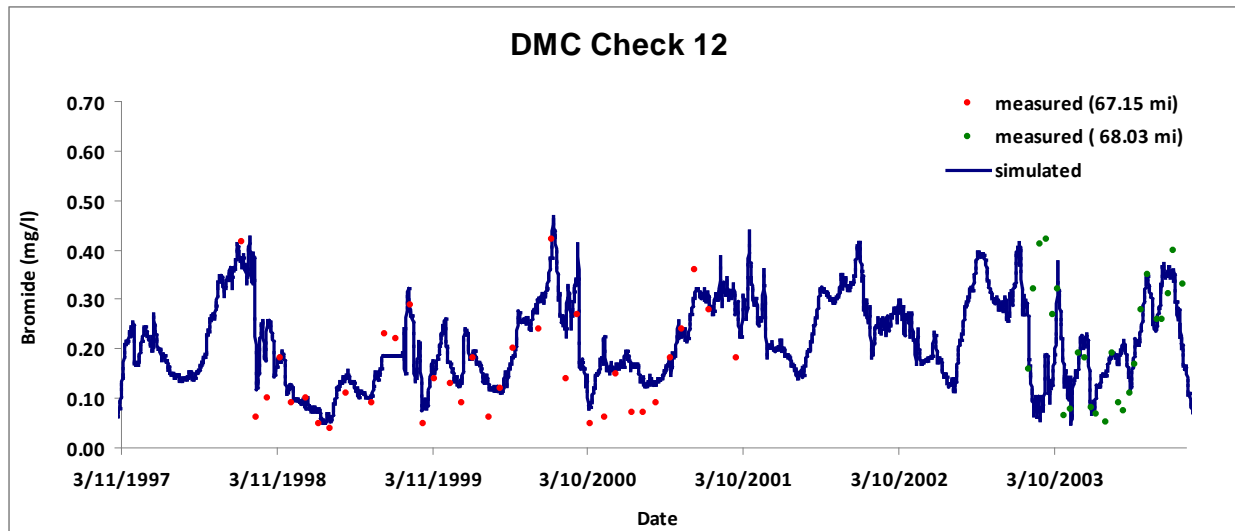


Figure 4.77 Comparison of Measured and Simulated Bromide at Del Valle Check 7, South Bay Aqueduct

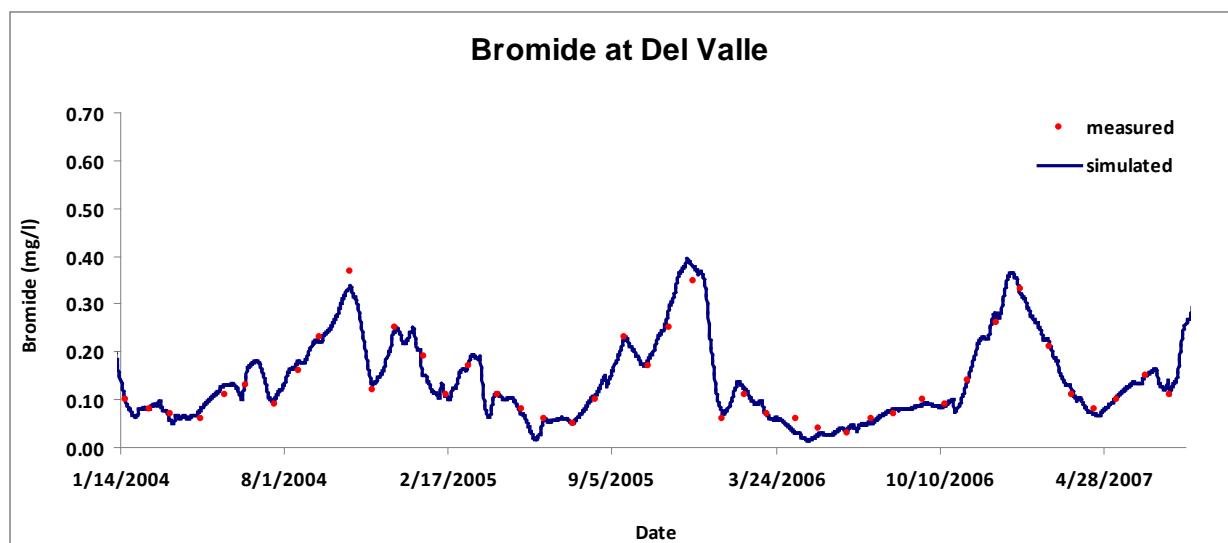
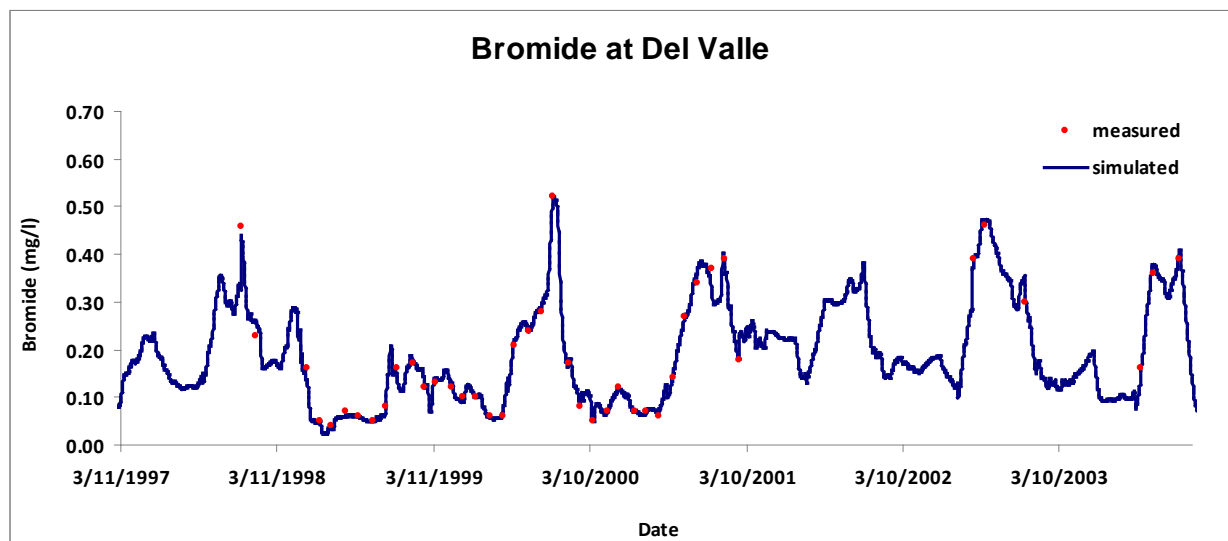


Figure 4.78 Scatter Plot for Bromide at California Aqueduct Check 13

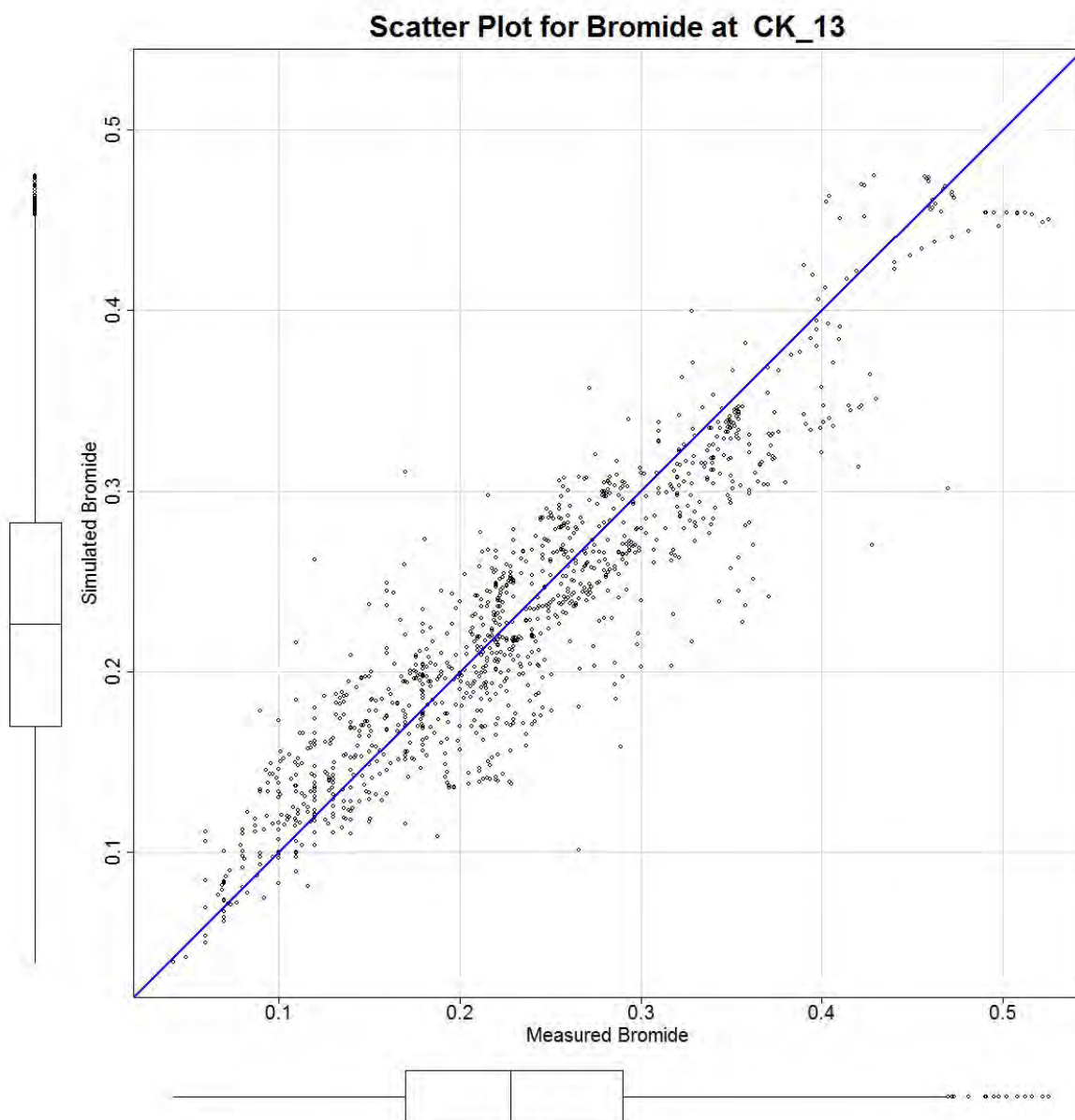


Figure 4.79 Scatter Plot for Bromide at California Aqueduct Check 21

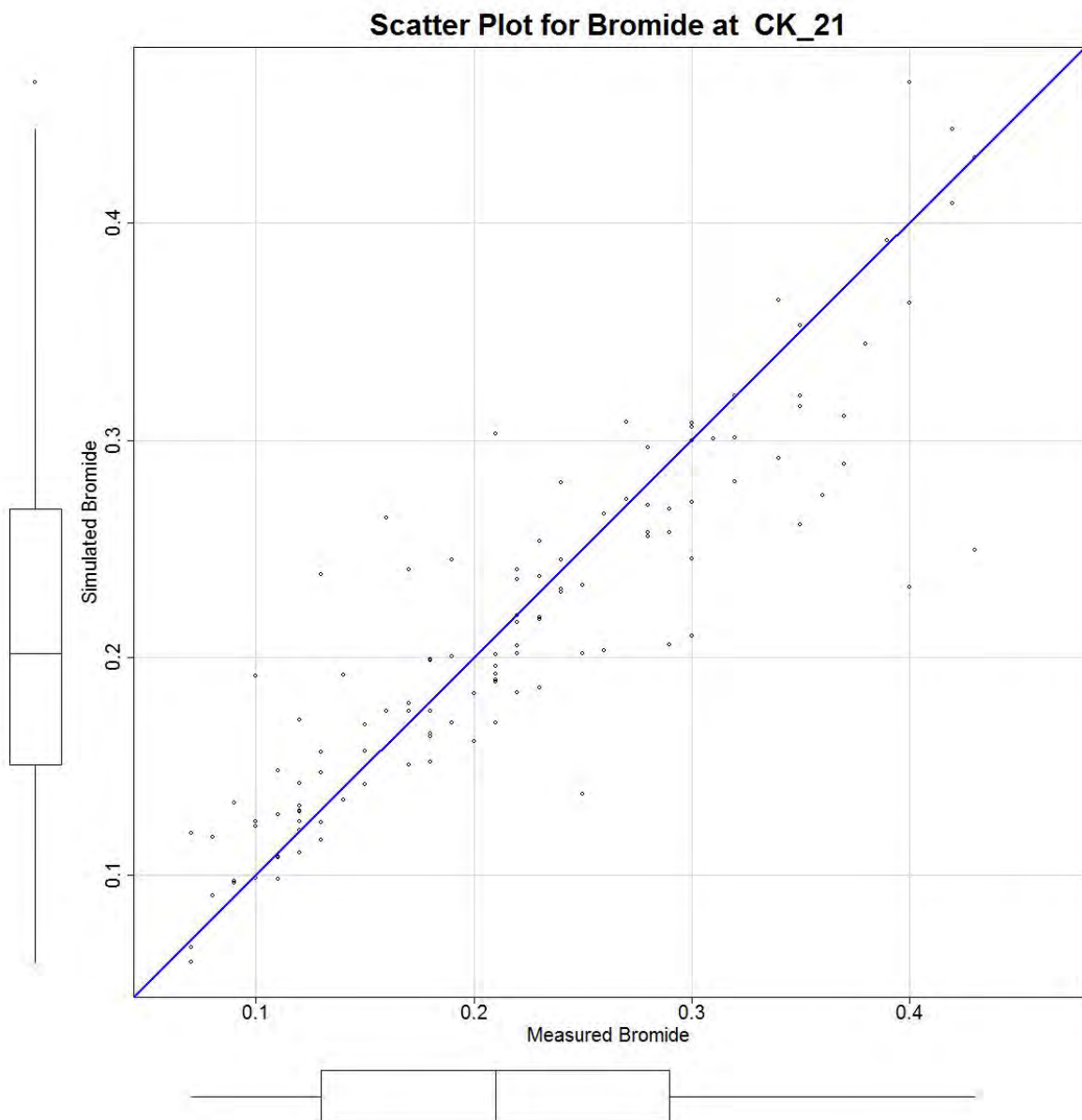


Figure 4.80 Scatter Plot for Bromide at California Aqueduct Check 29

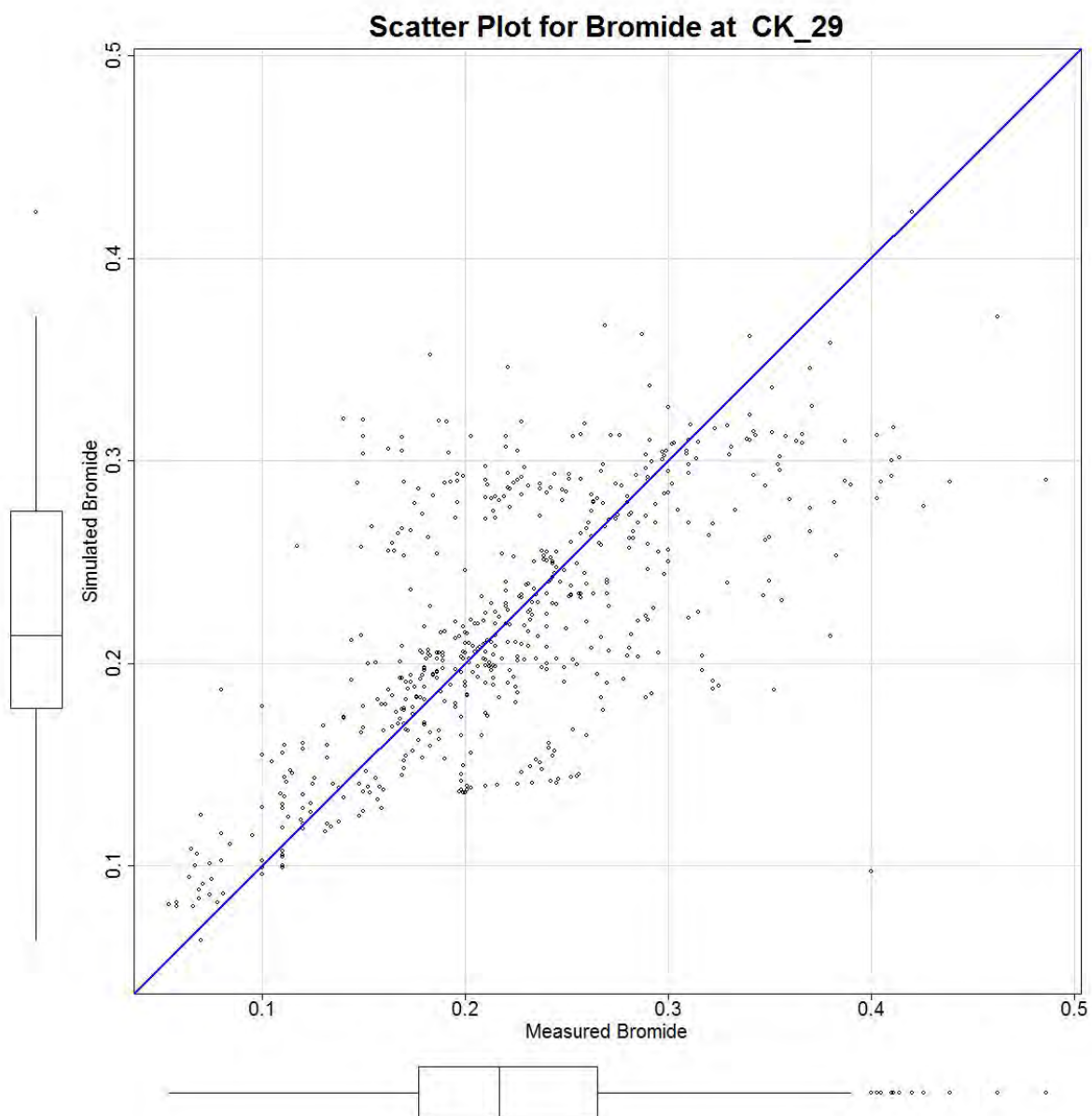


Figure 4.81 Scatter Plot for Bromide at California Aqueduct Check 41

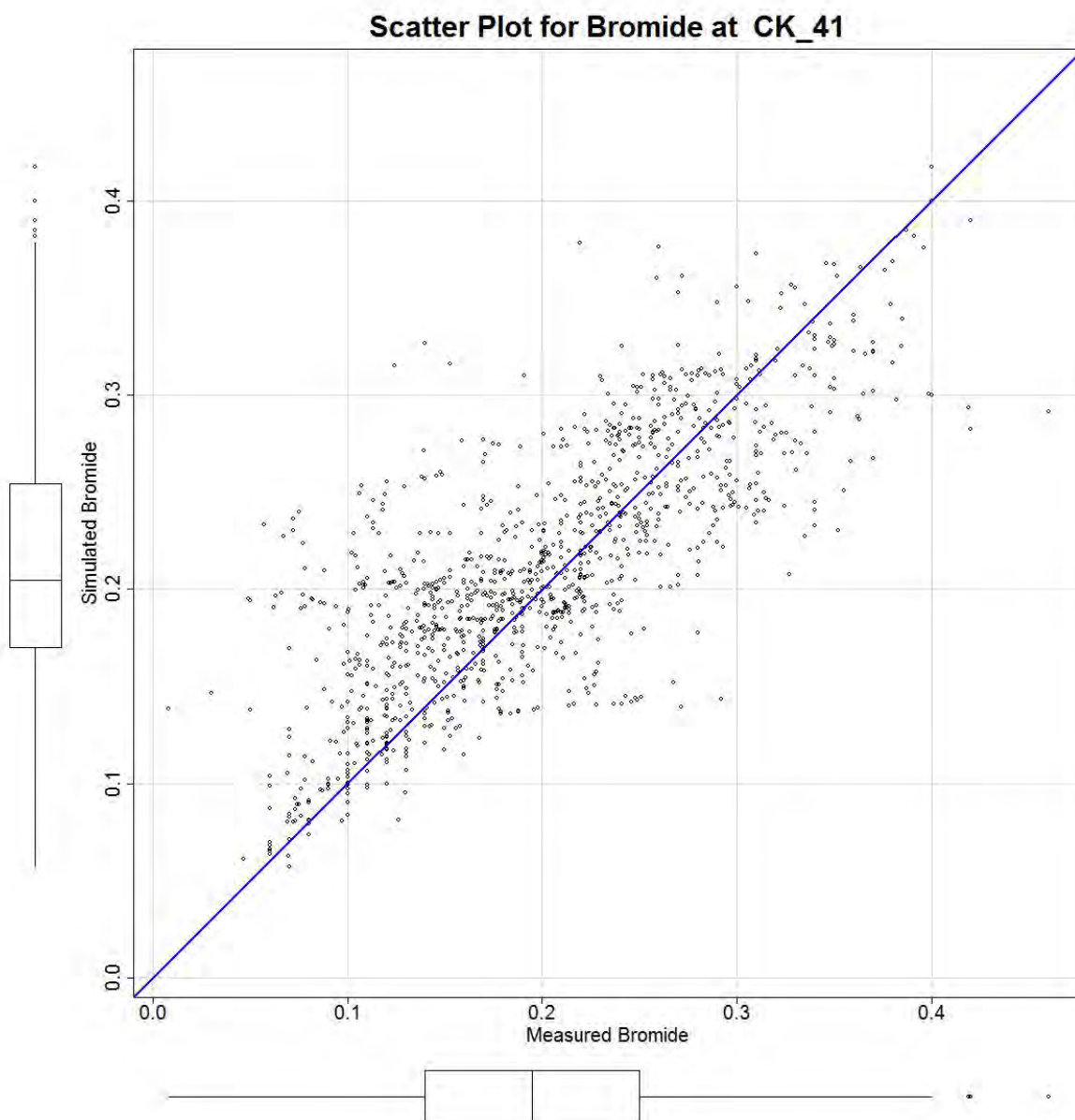


Figure 4.82 Scatter Plot for Bromide at California Aqueduct Check 66

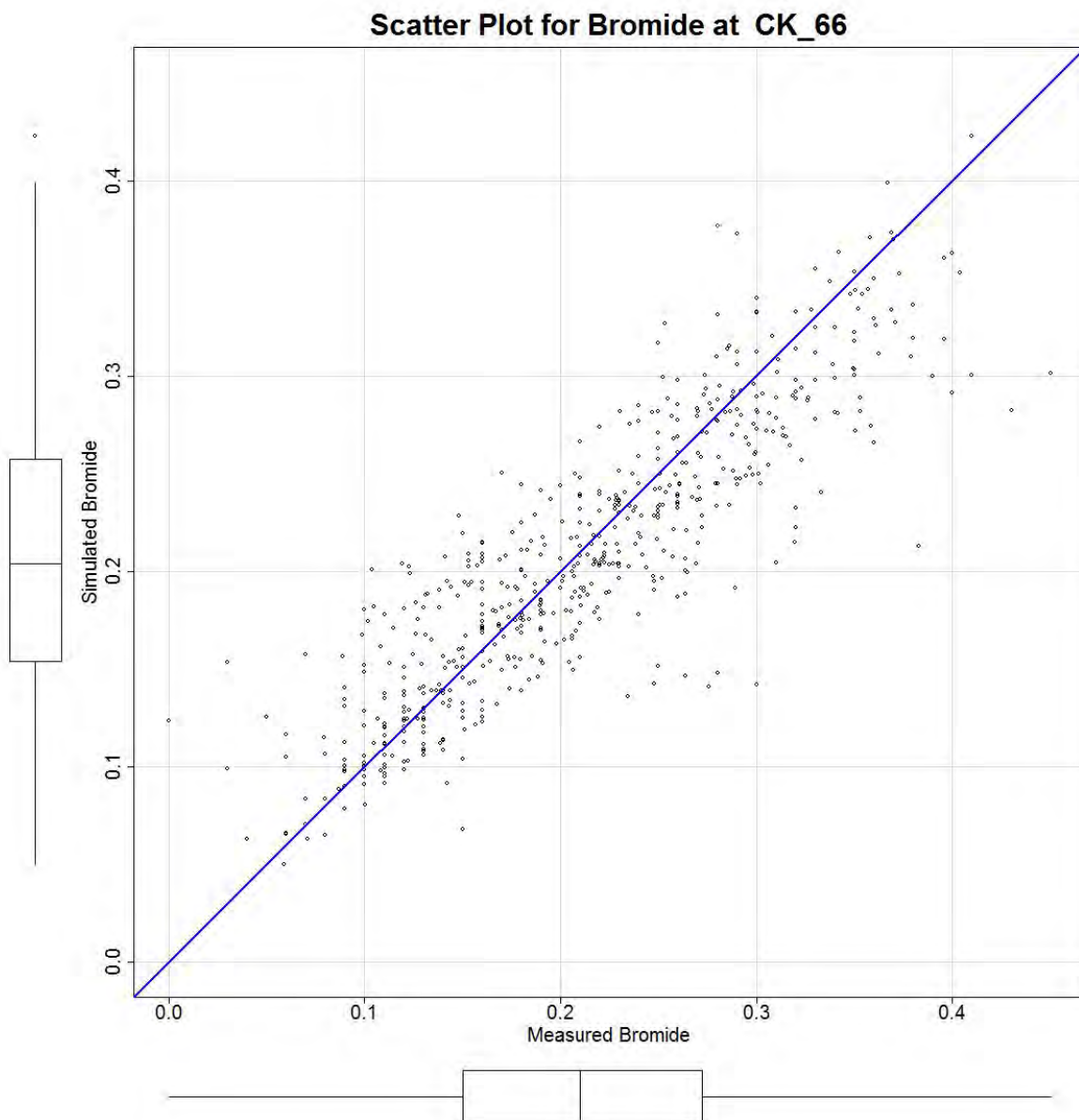


Figure 4.83 Scatter Plot for Bromide at Del Valle Check 7, South Bay Aqueduct

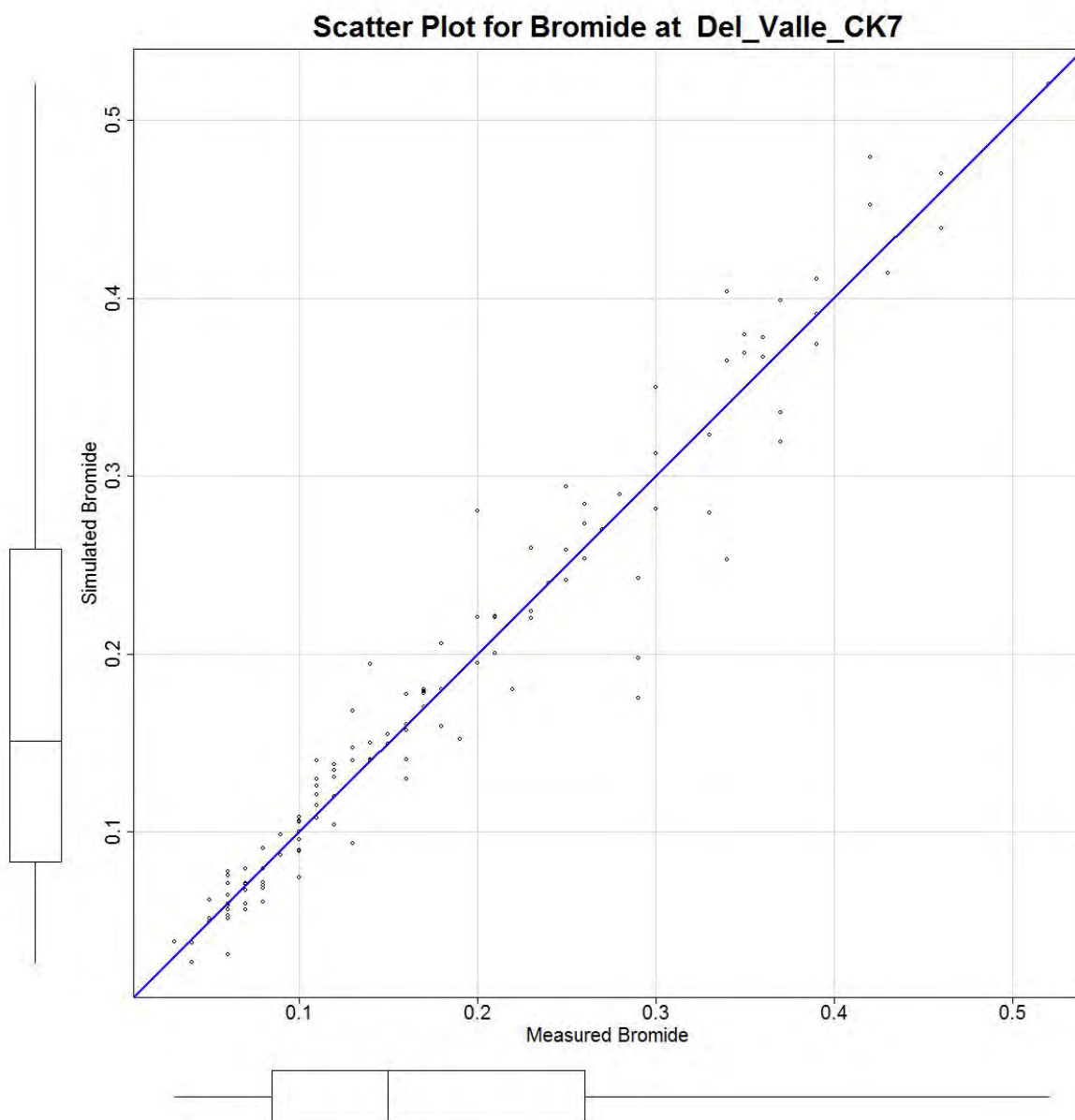


Figure 4.84 Scatter Plot for Bromide at DMC Check 12

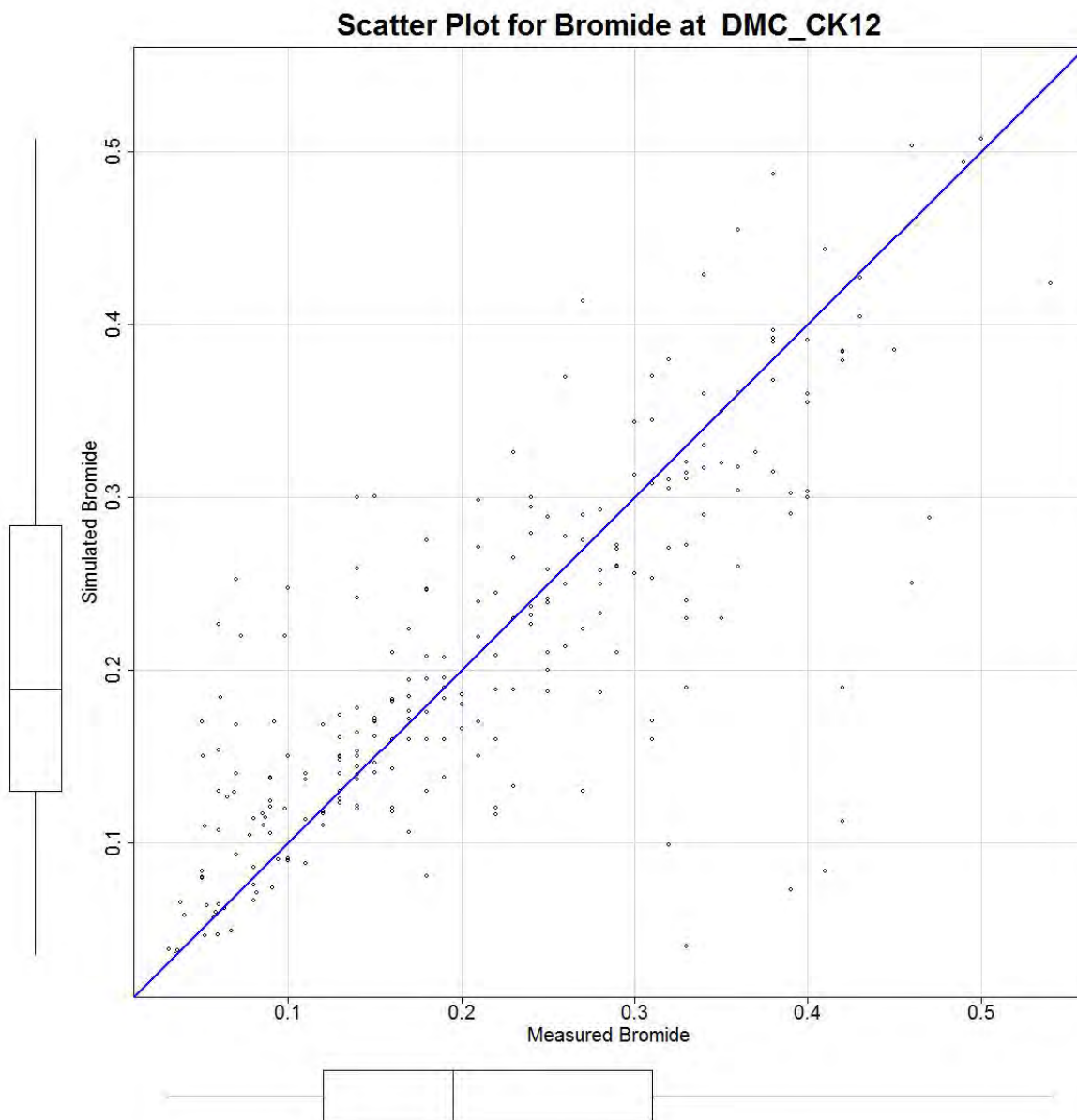


Figure 4.85 Scatter Plot for Bromide at San Luis Reservoir

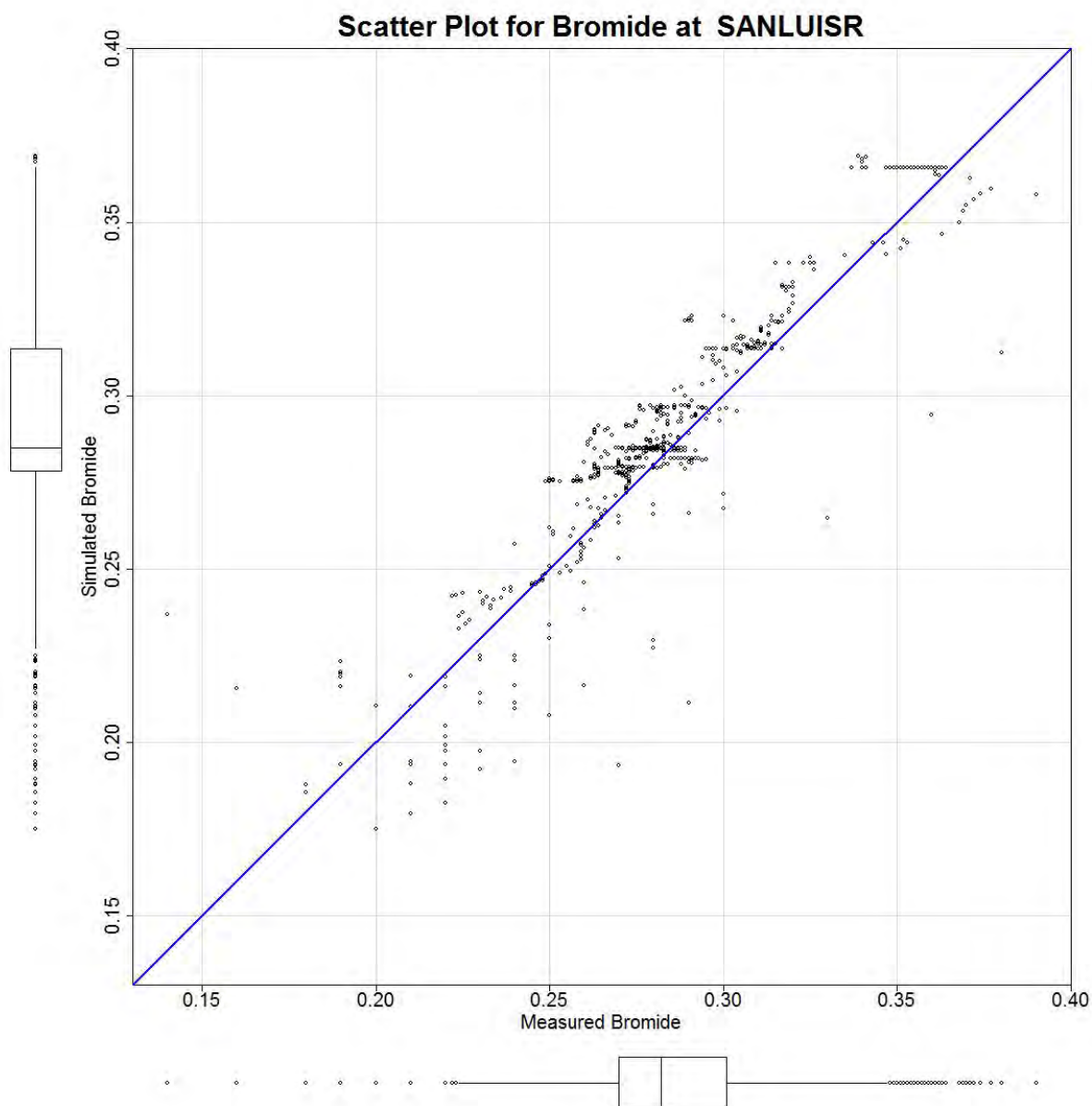


Figure 4.86 Exceedance Curve for Bromide at California Aqueduct Check 13

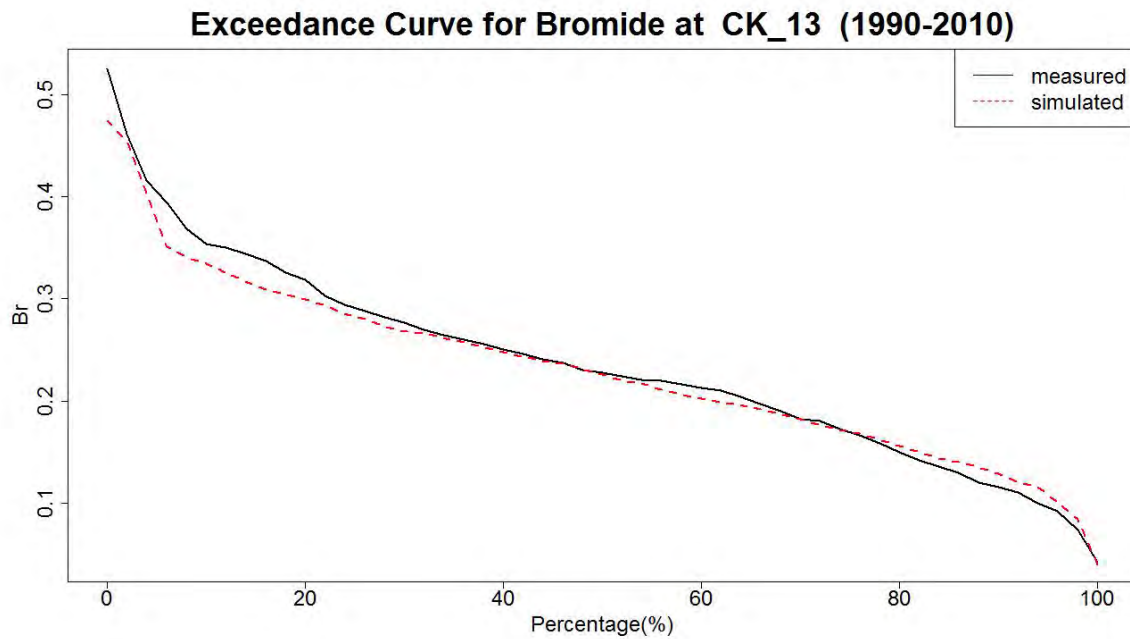


Figure 4.87 Exceedance Curve for Bromide at California Aqueduct Check 21

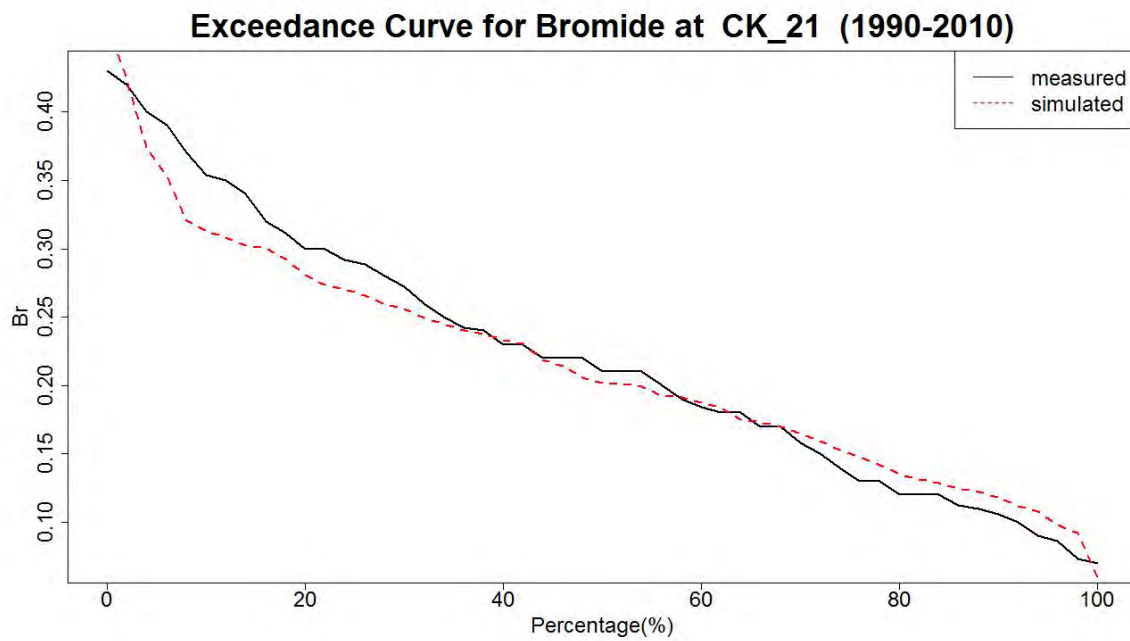


Figure 4.88 Exceedance Curve for Bromide at California Aqueduct Check 29

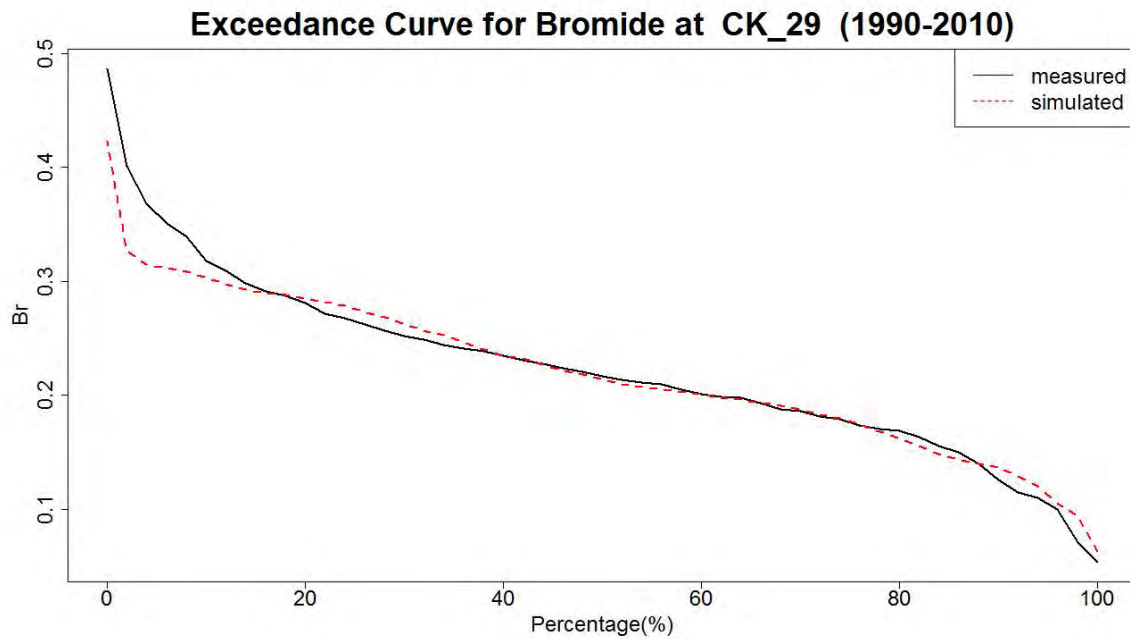


Figure 4.89 Exceedance Curve for Bromide at California Aqueduct Check 41

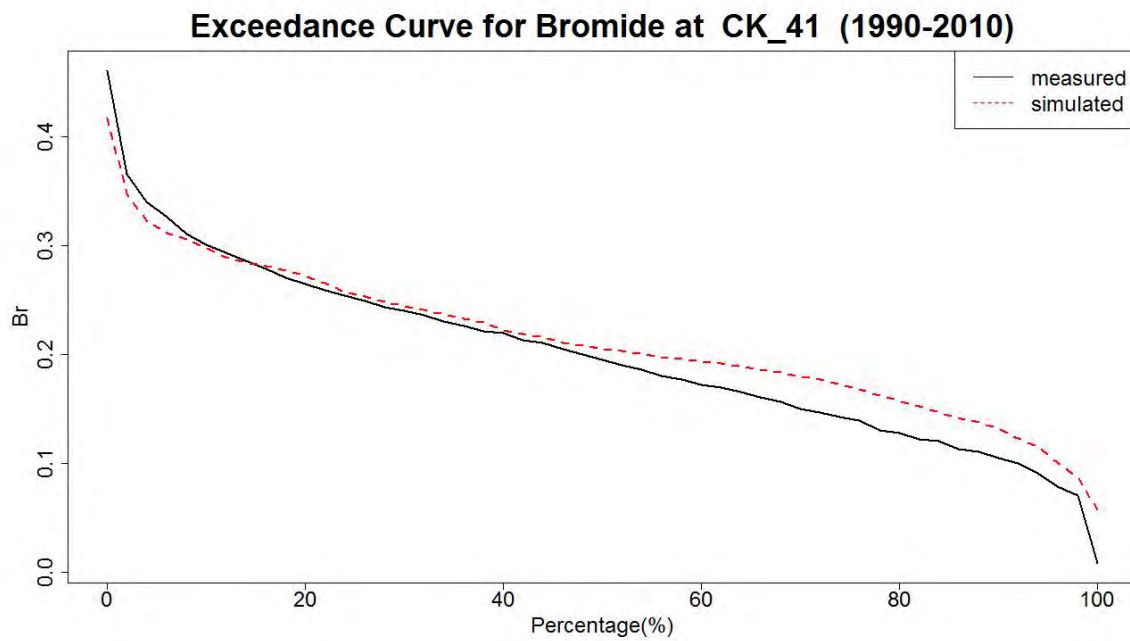


Figure 4.90 Exceedance Curve for Bromide at California Aqueduct Check 66

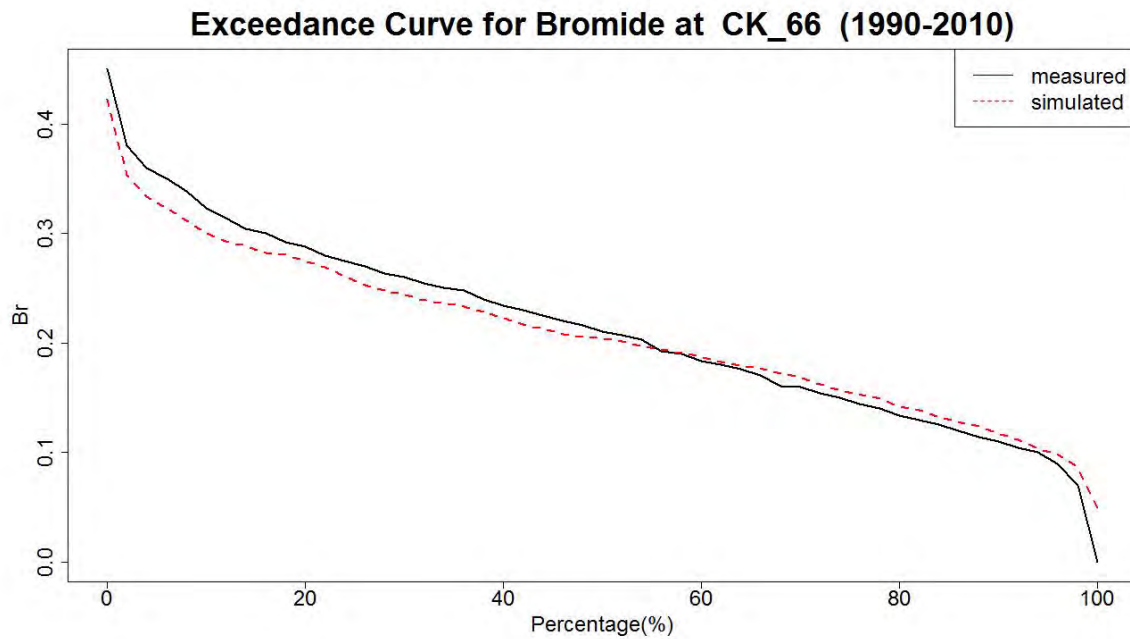


Figure 4.91 Exceedance Curve for Bromide at Del Valle Check 7, South Bay Aqueduct

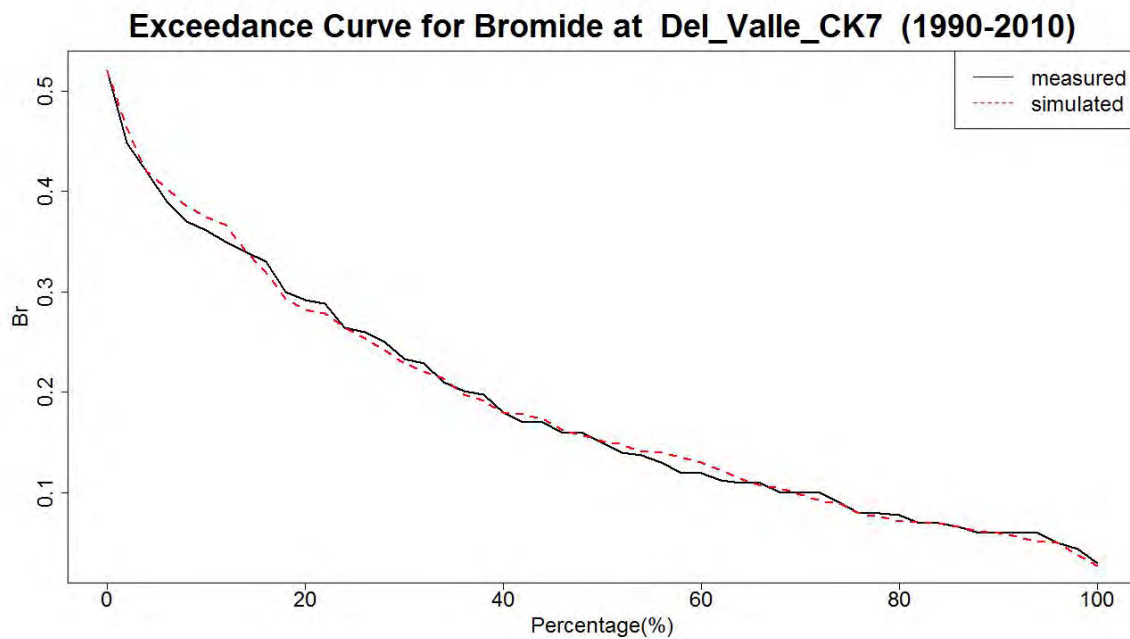


Figure 4.92 Exceedance Curve for Bromide at DMC Check 12

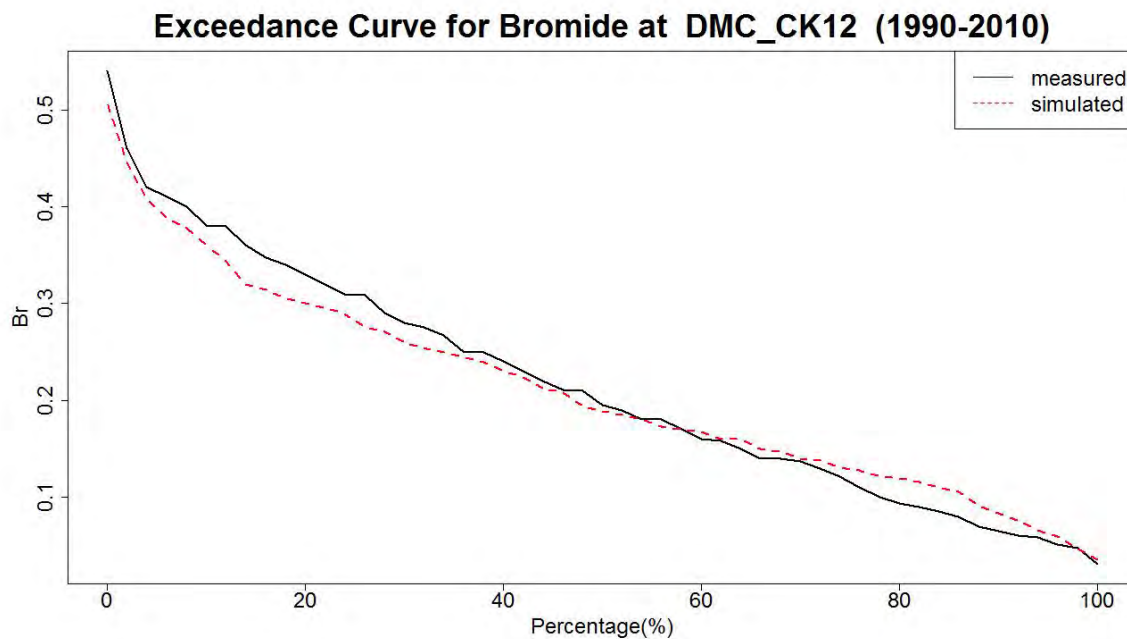


Figure 4.93 Exceedance Curve for Bromide at San Luis Reservoir

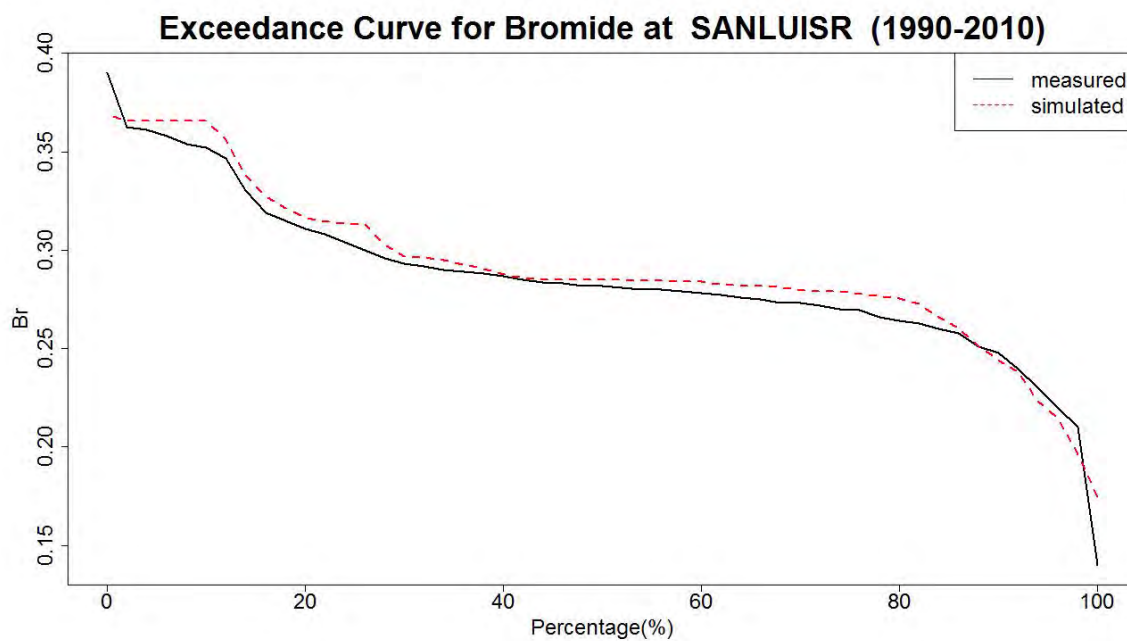


Figure 4.94 Month by Month Comparison of Measured and Simulated Bromide at California Aqueduct Check 13

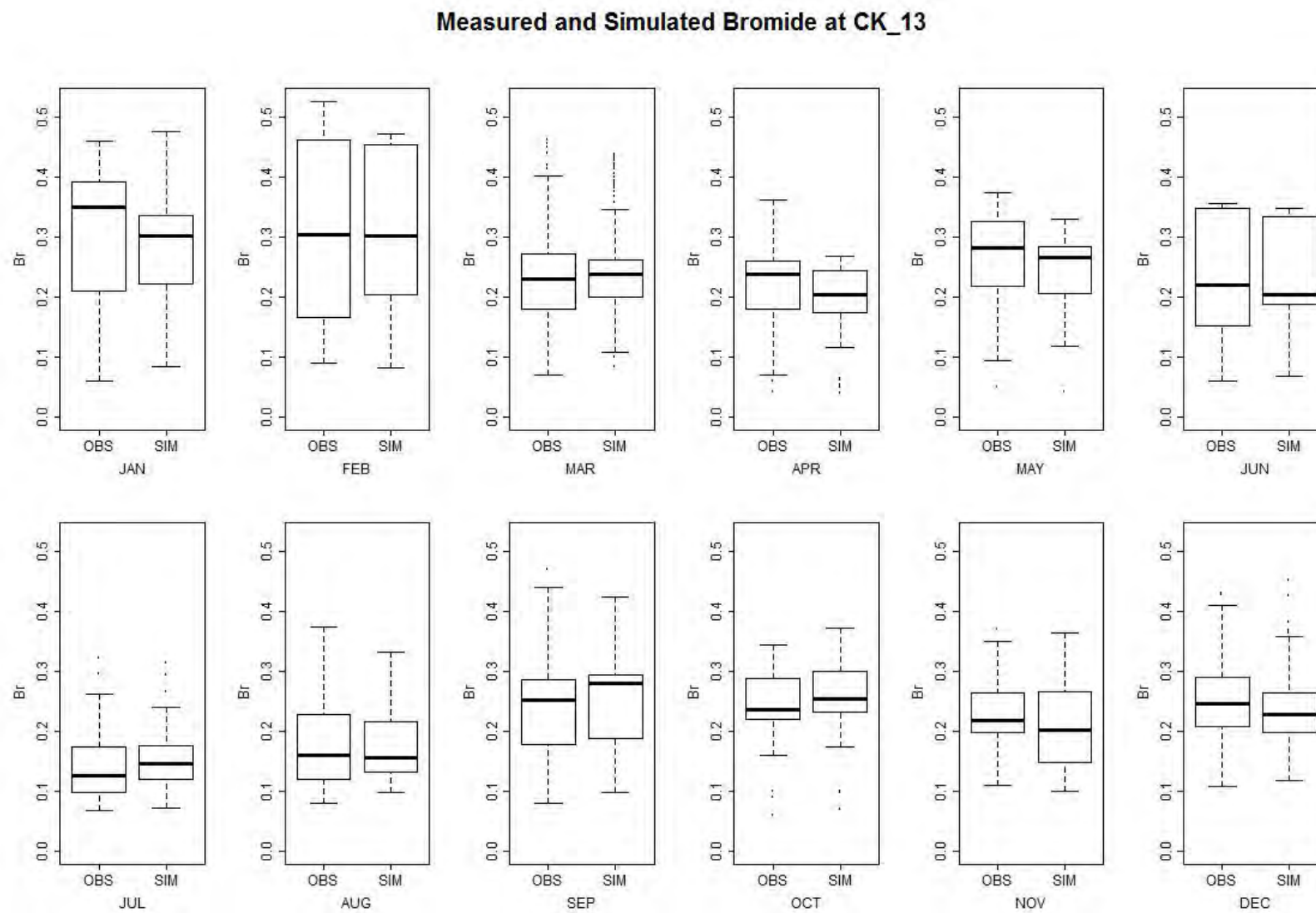


Figure 4.95 Month by Month Comparison of Measured and Simulated Bromide at California Aqueduct Check 21

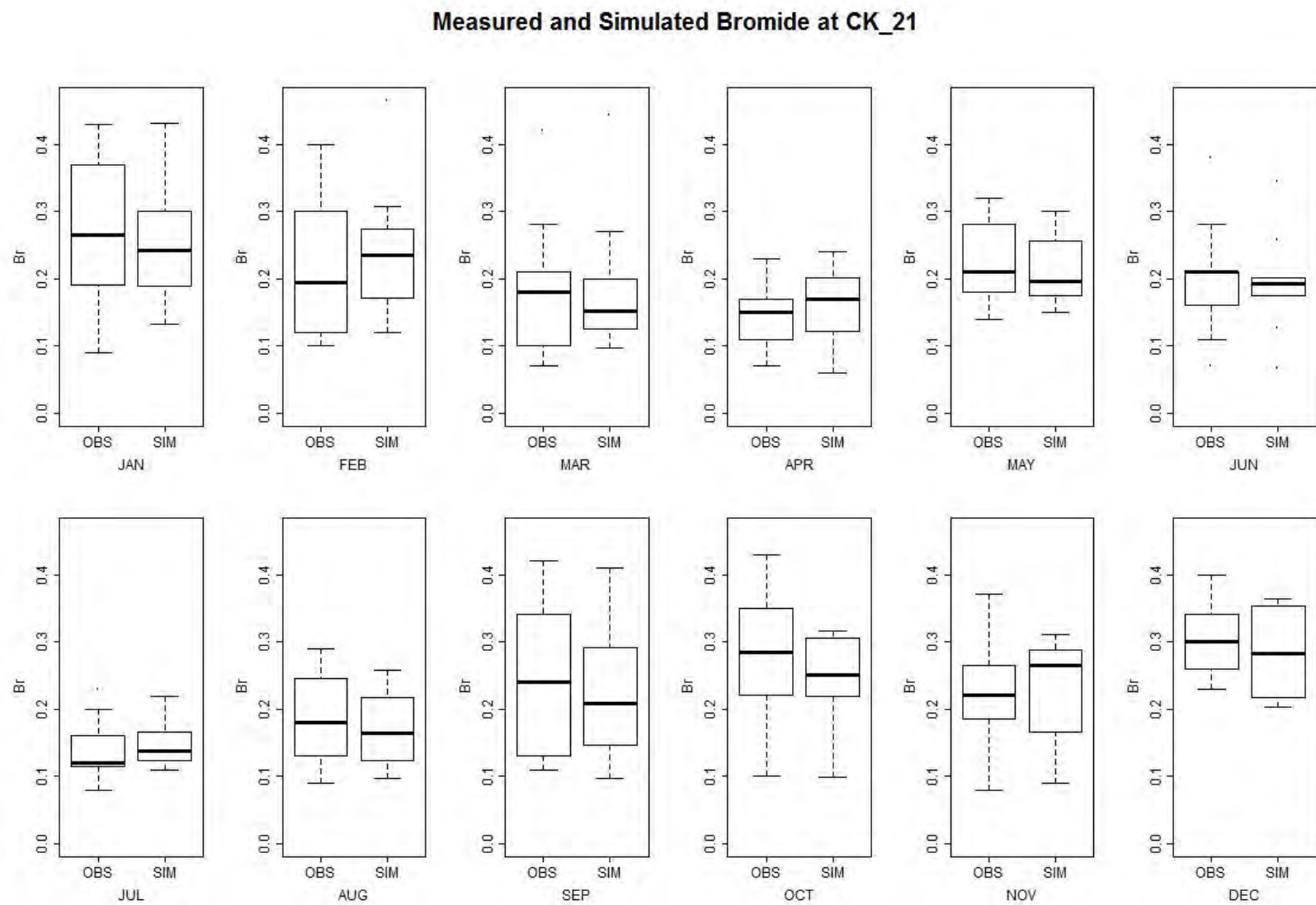


Figure 4.96 Month by Month Comparison of Measured and Simulated Bromide at California Aqueduct Check 29

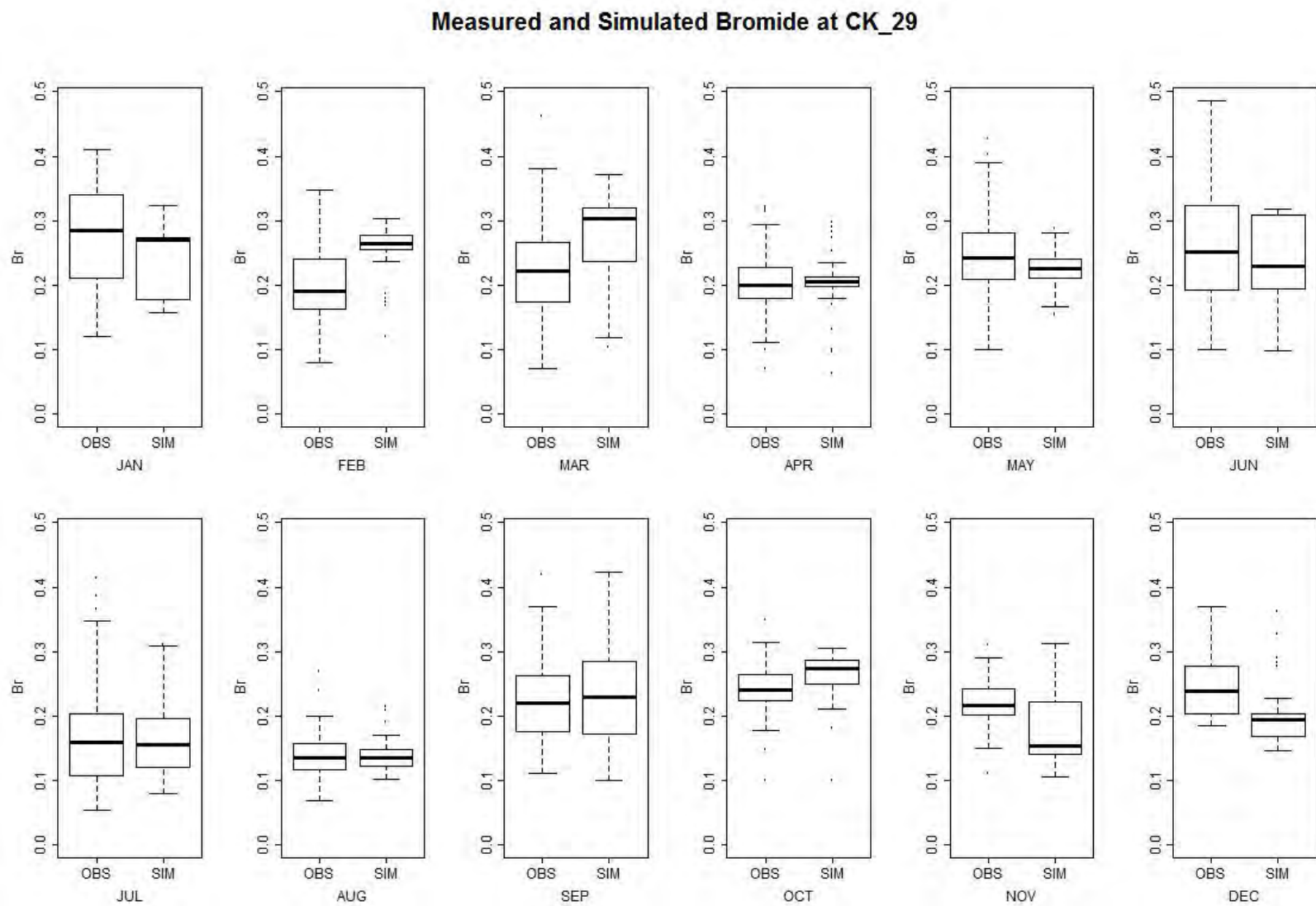


Figure 4.97 Month by Month Comparison of Measured and Simulated Bromide at California Aqueduct Check 41

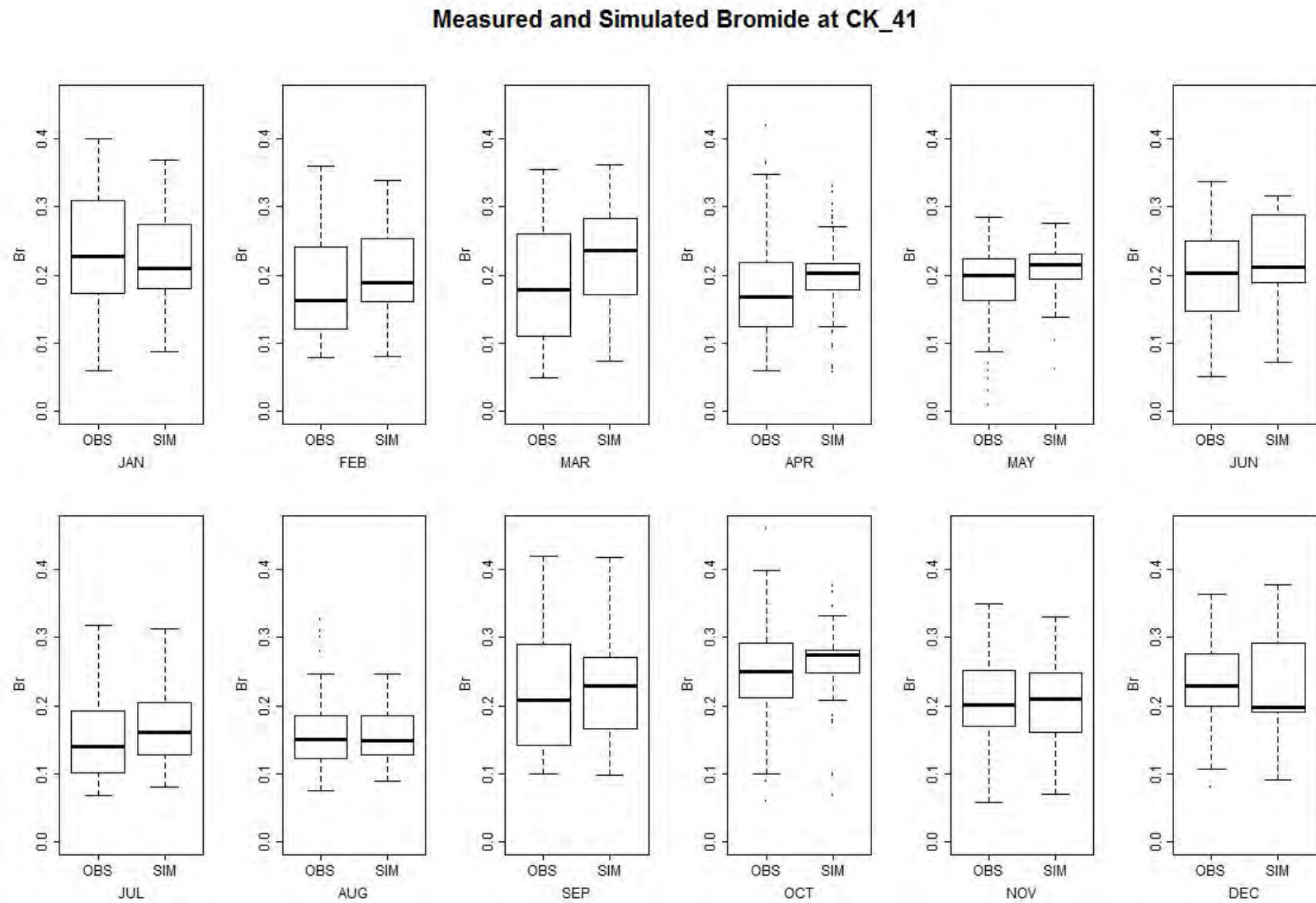


Figure 4.98 Month by Month Comparison of Measured and Simulated Bromide at California Aqueduct Check 66

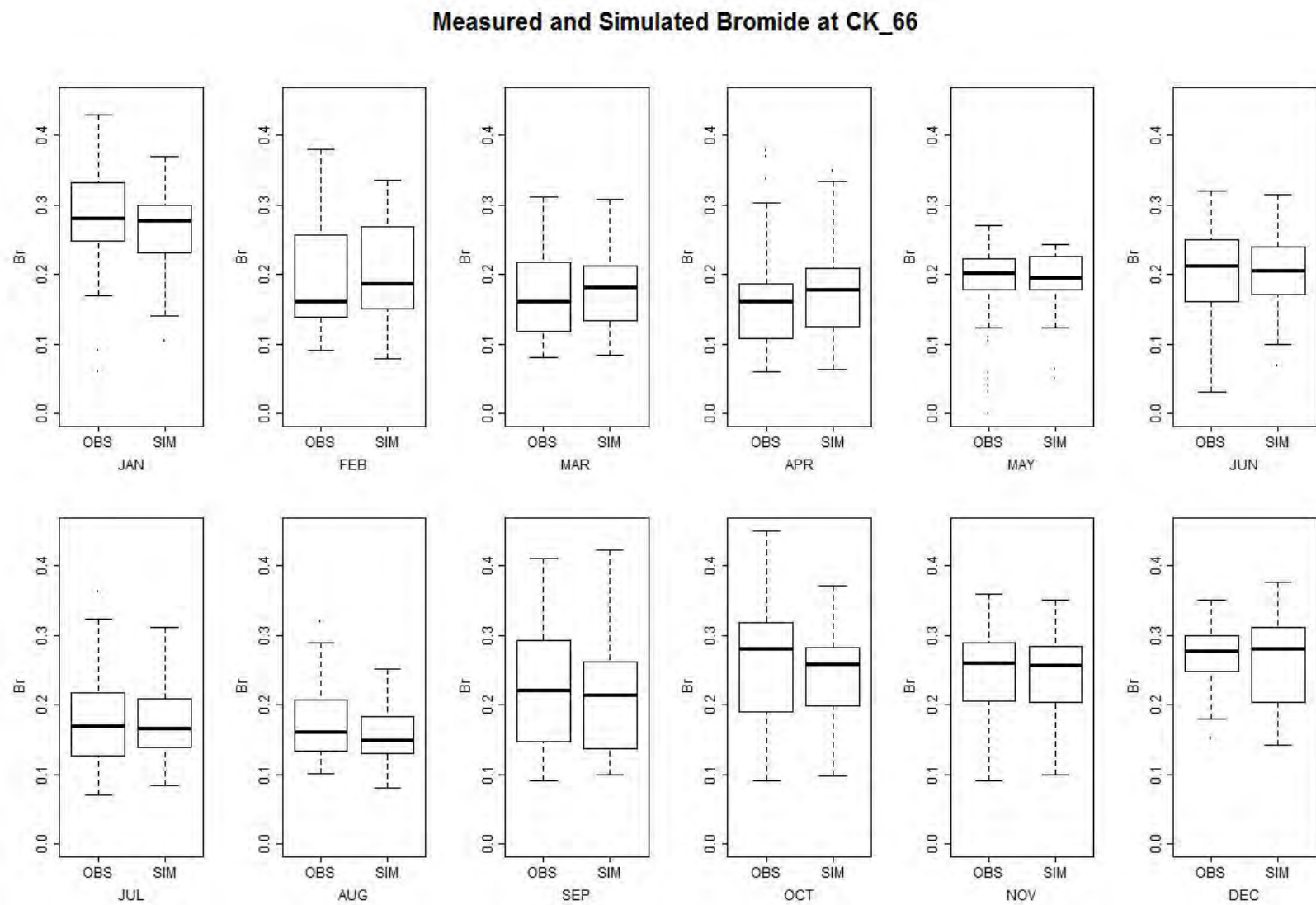


Figure 4.99 Month by Month Comparison of Measured and Simulated Bromide at Del Valle Check 7, South Bay Aqueduct

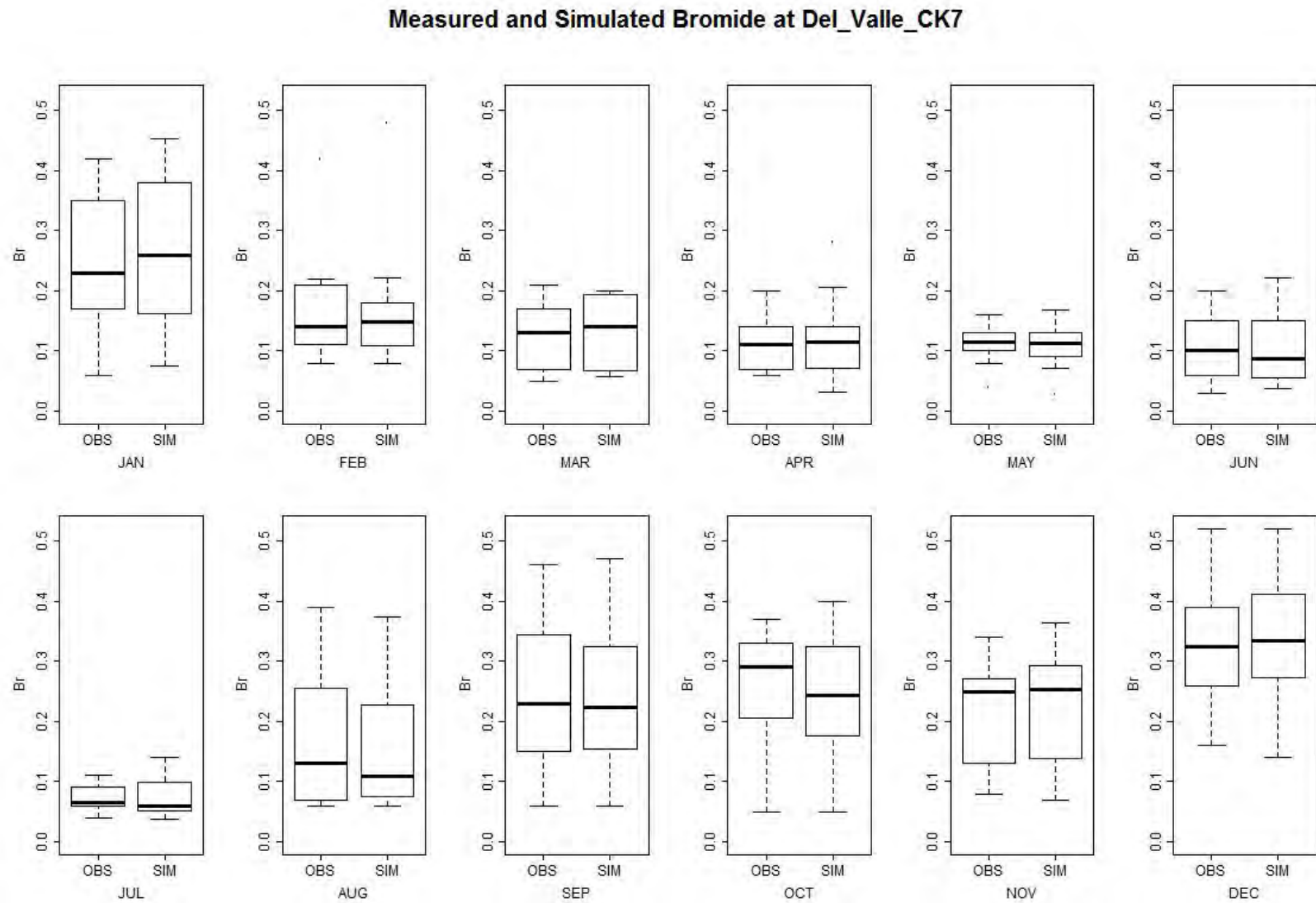


Figure 4.100 Month by Month Comparison of Measured and Simulated Bromide at DMC Check 12

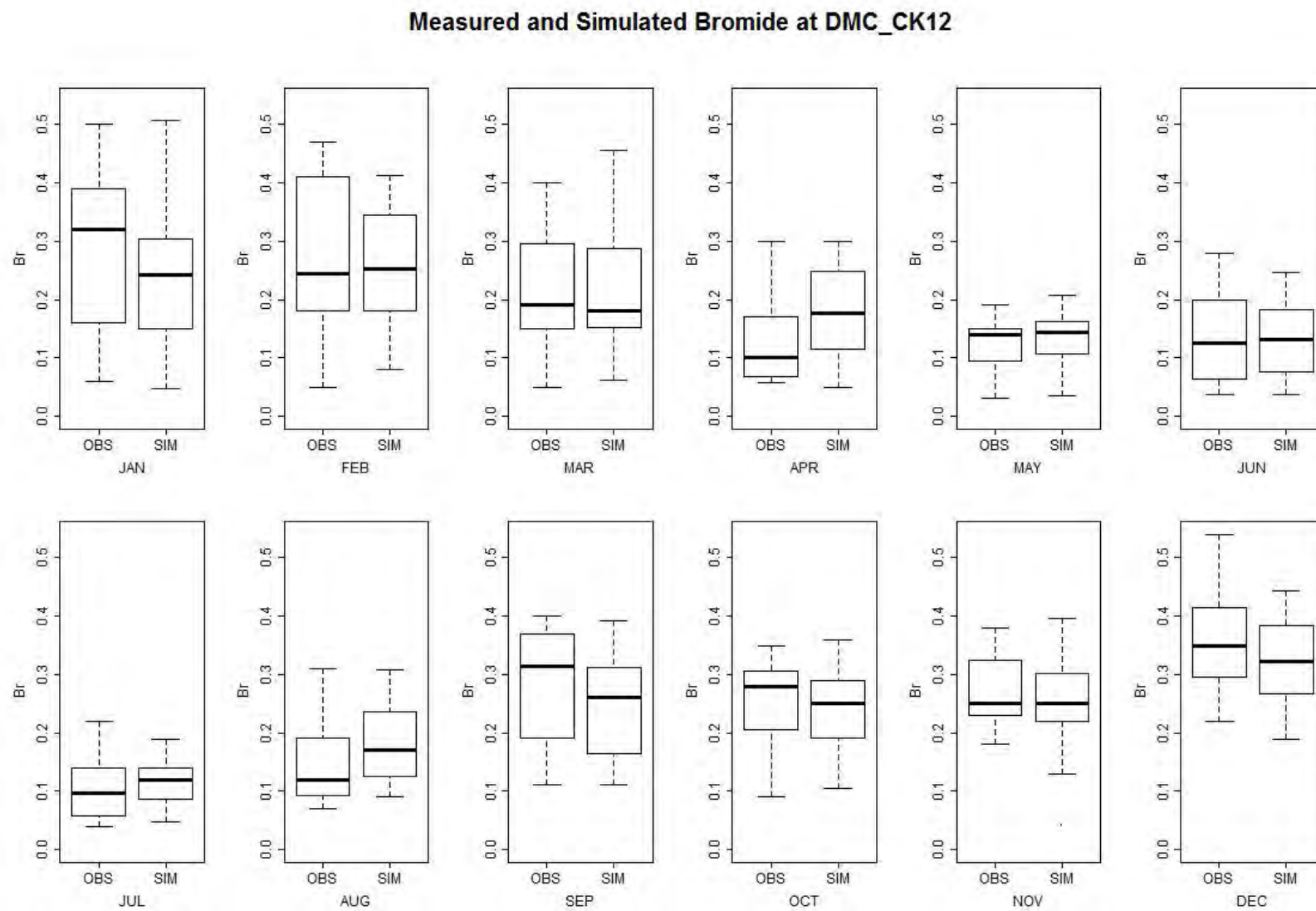


Figure 4.101 Month by Month Comparison of Measured and Simulated Bromide at San Luis Reservoir

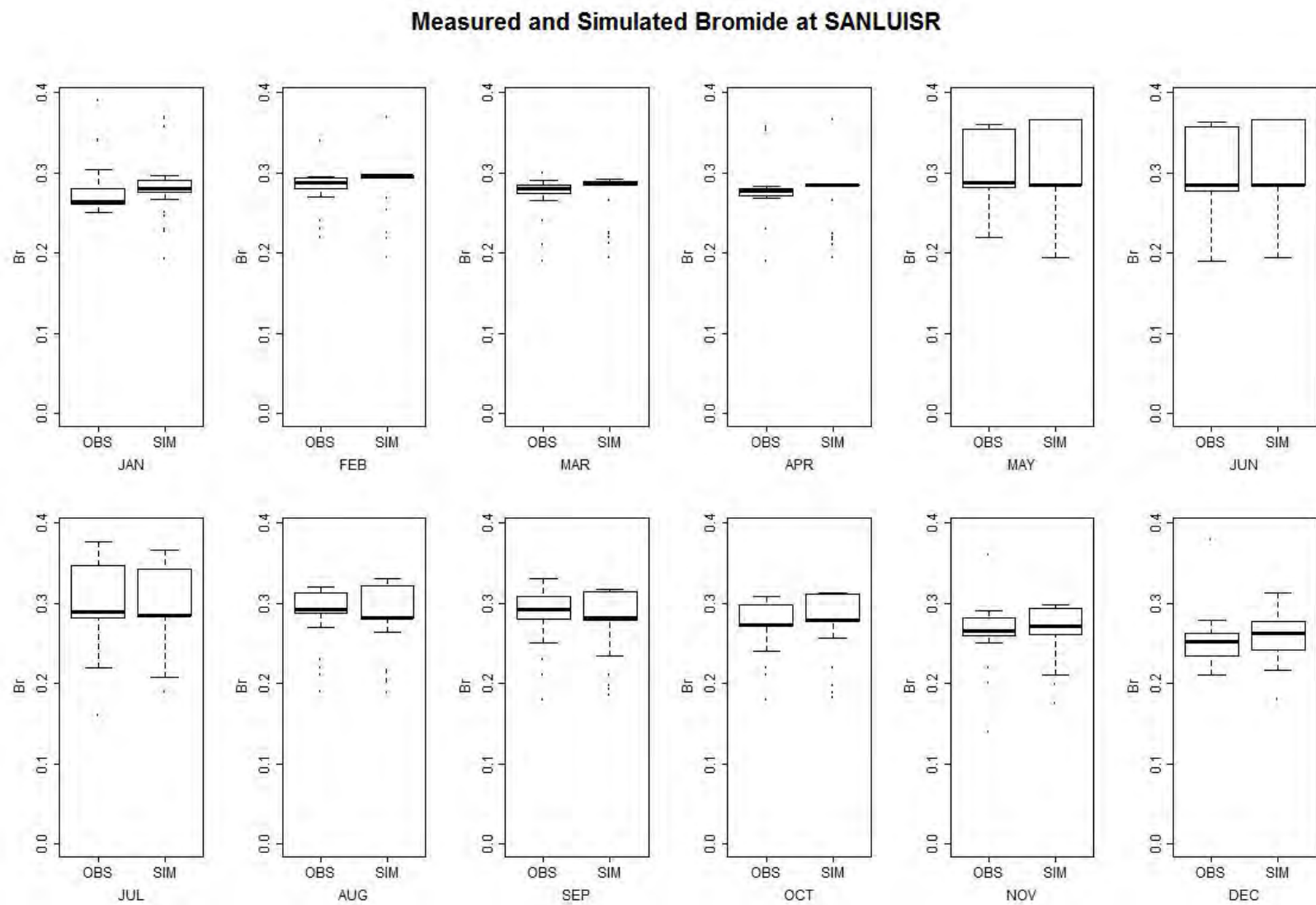


Figure 4.102 Comparison of Measured and Simulated DOC at California Aqueduct Check 12

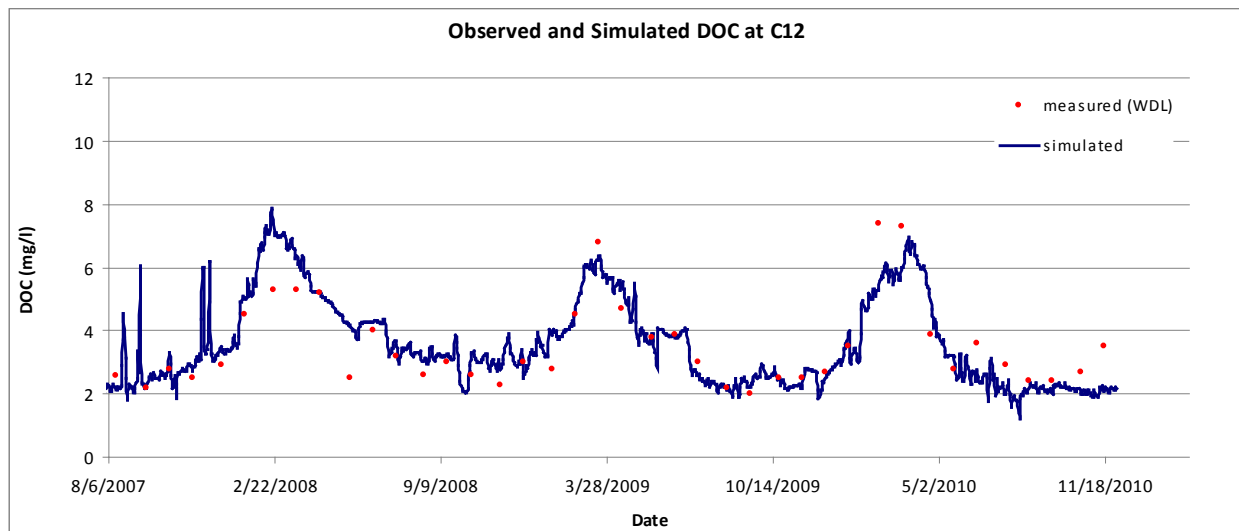
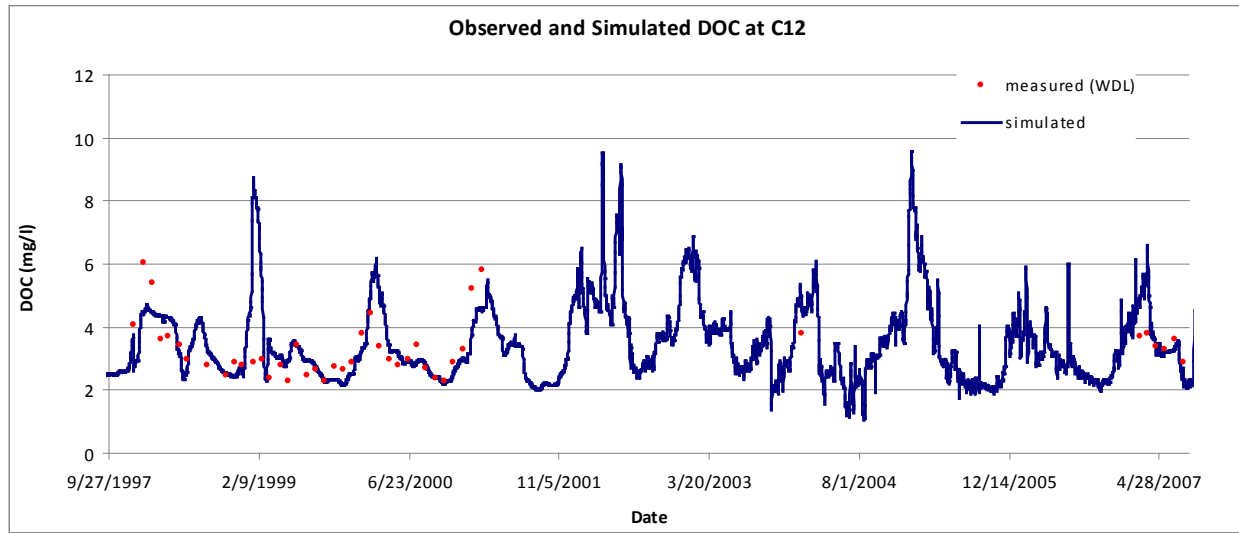


Figure 4.103 Comparison of Measured and Simulated DOC at California Aqueduct Check 13

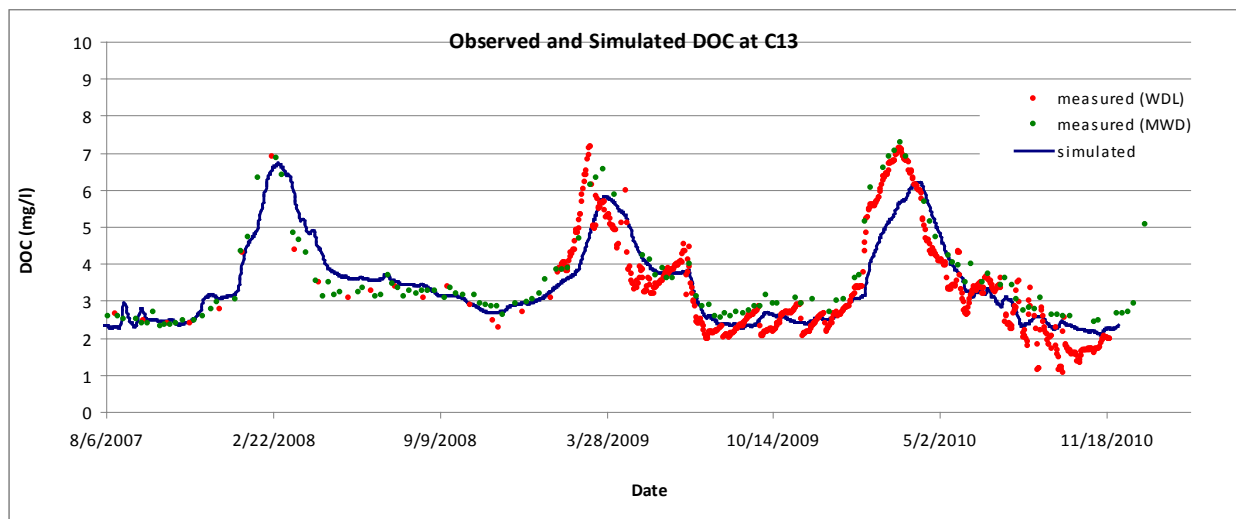
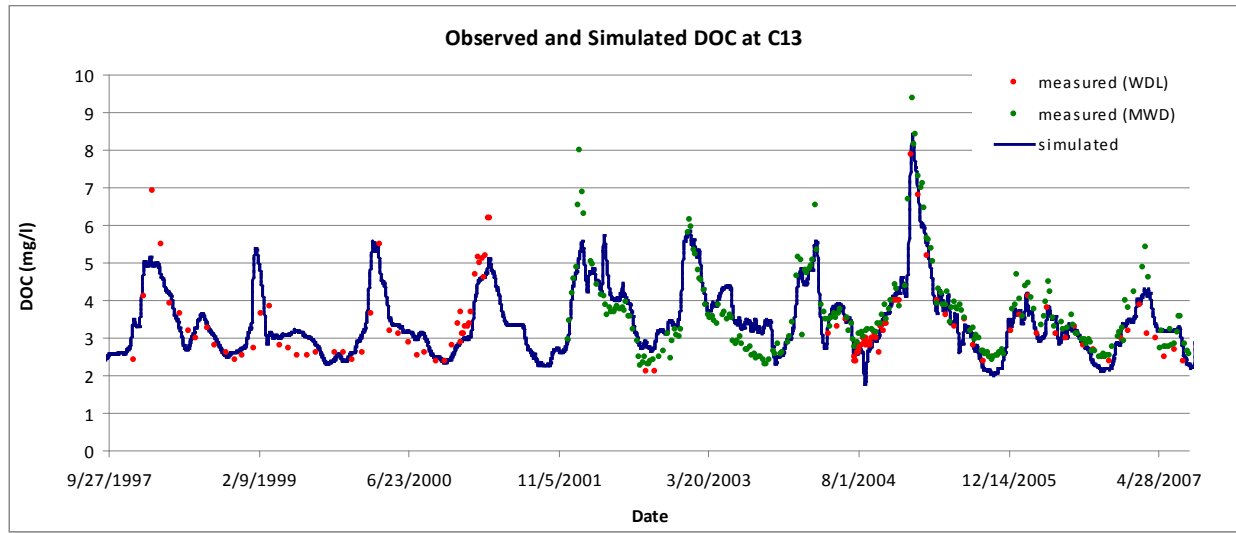


Figure 4.104 Comparison of Measured and Simulated DOC at California Aqueduct Check 21

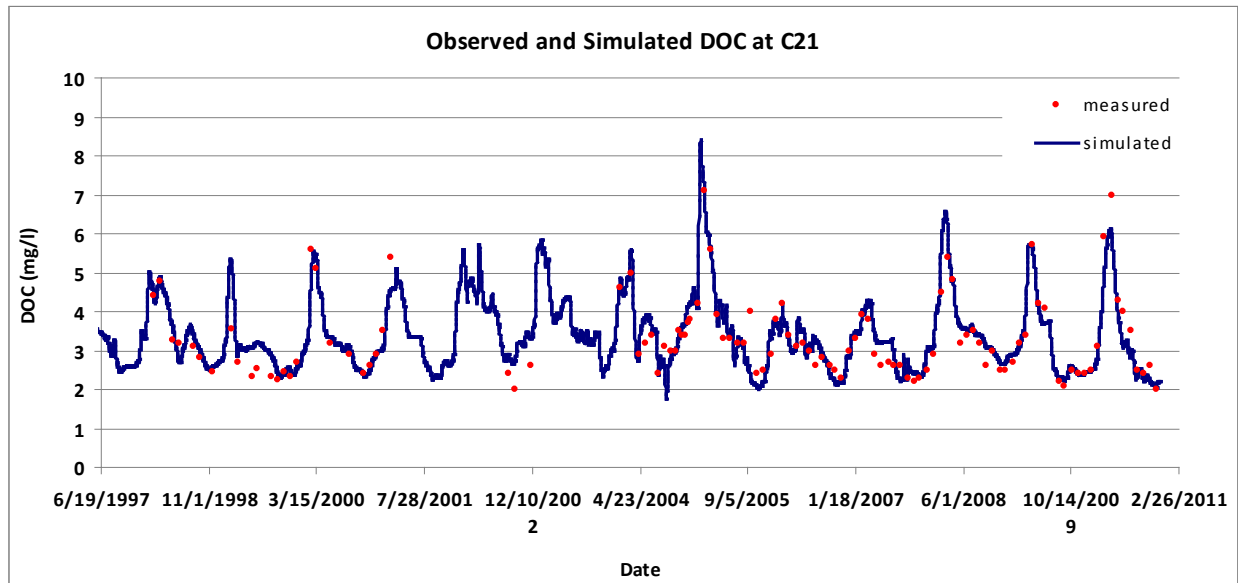


Figure 4.105 Comparison of Measured and Simulated DOC at California Aqueduct Check 29

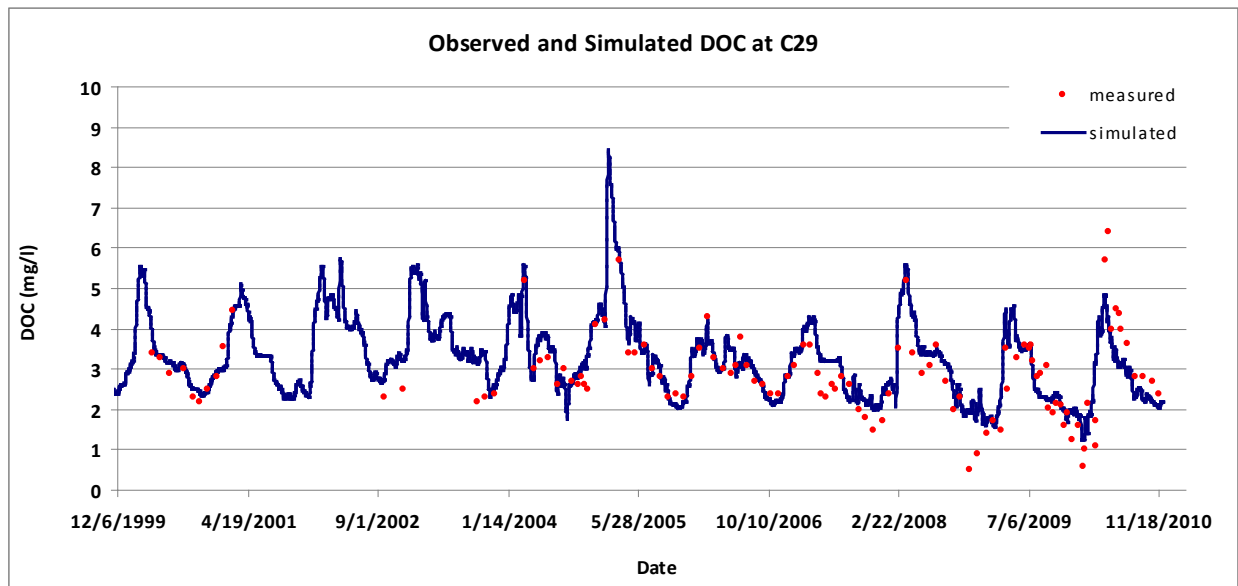


Figure 4.106 Comparison of Measured and Simulated DOC at California Aqueduct Check 41

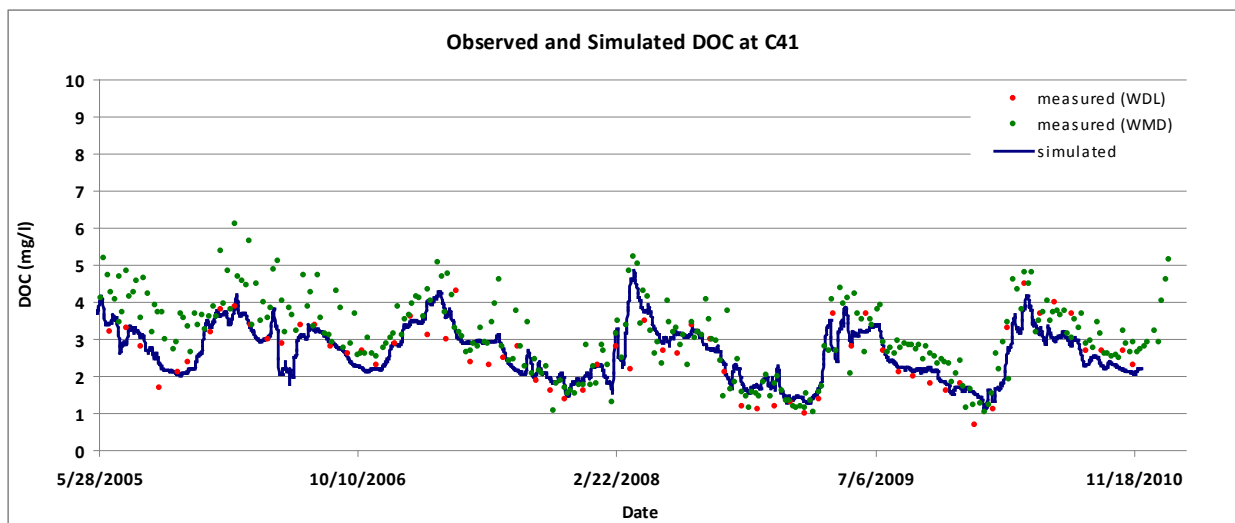
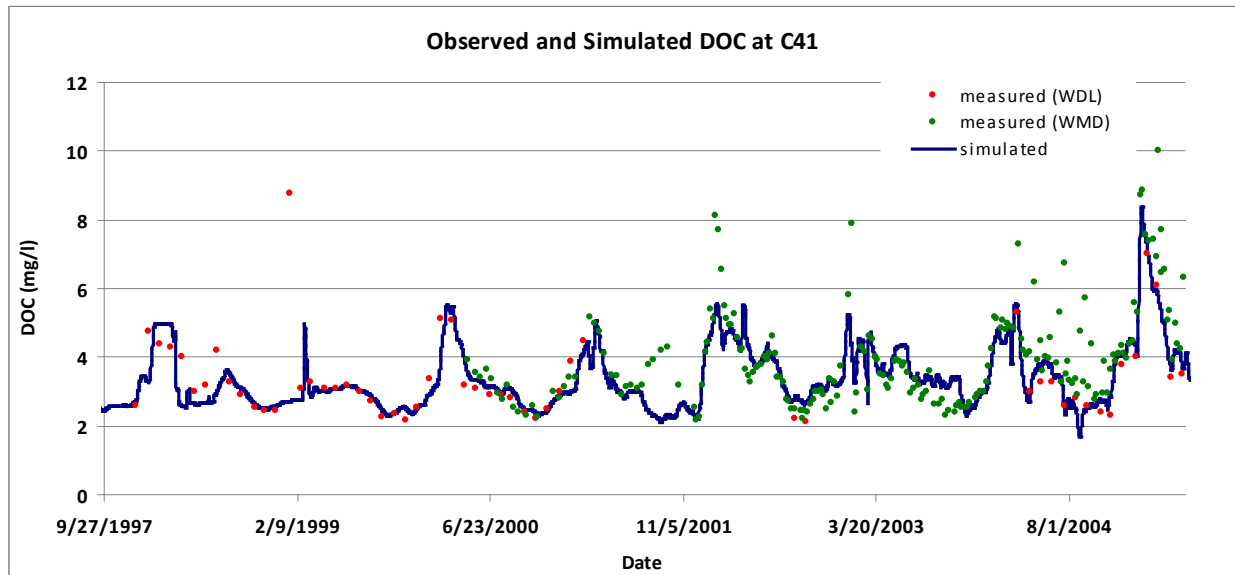


Figure 4.107 Comparison of Measured and Simulated DOC at California Aqueduct Check 66

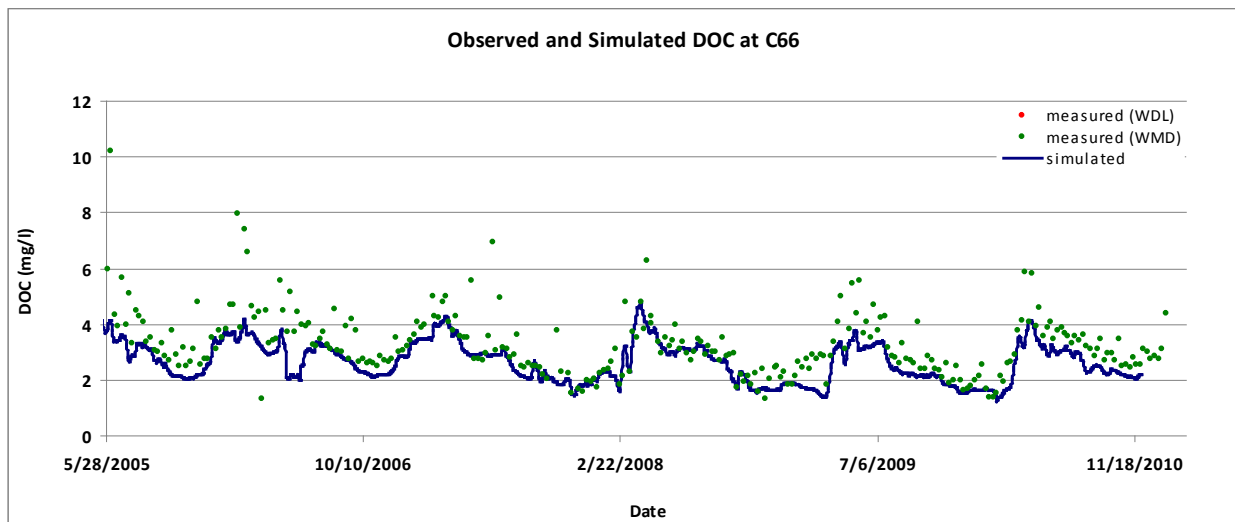
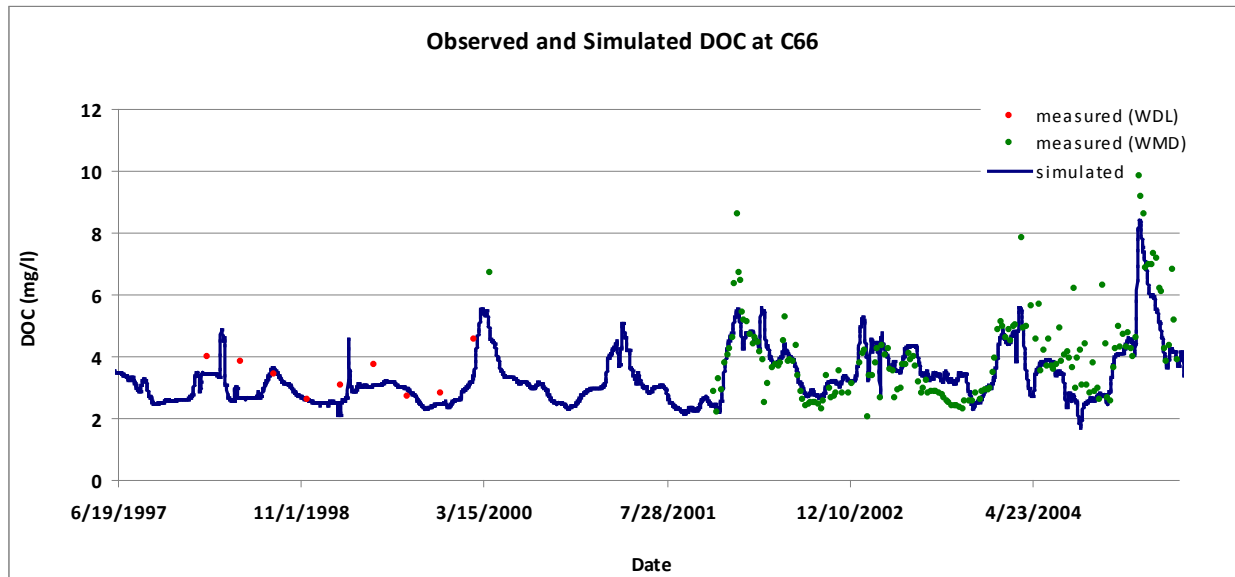


Figure 4.108 Comparison of Measured and Simulated DOC at San Luis Reservoir

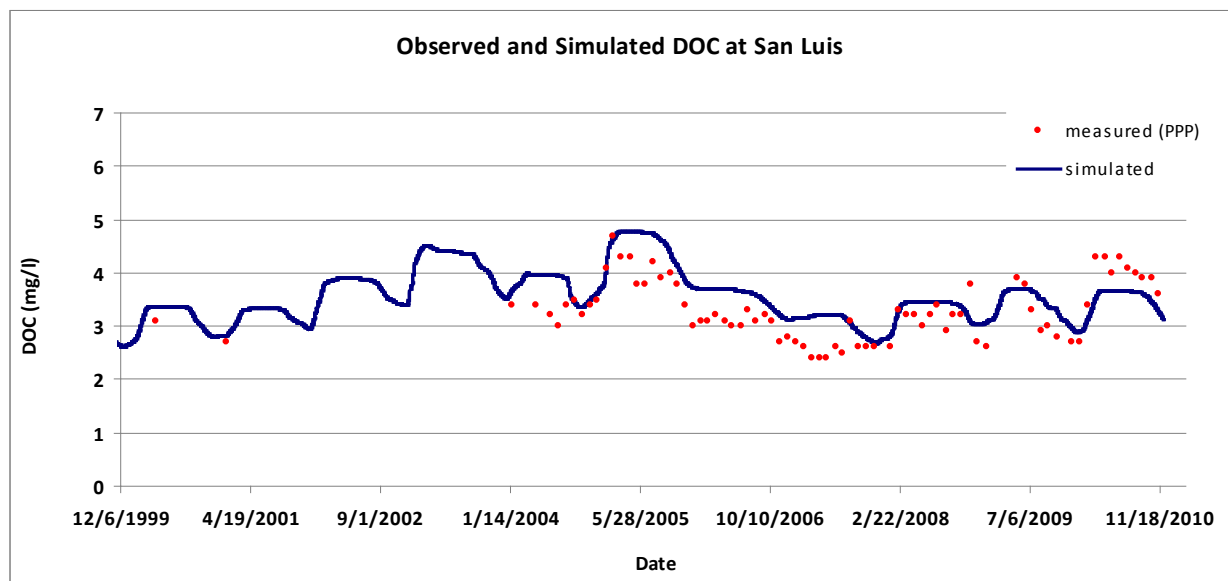


Figure 4.109 Comparison of Measured and Simulated DOC at DMC Check 12

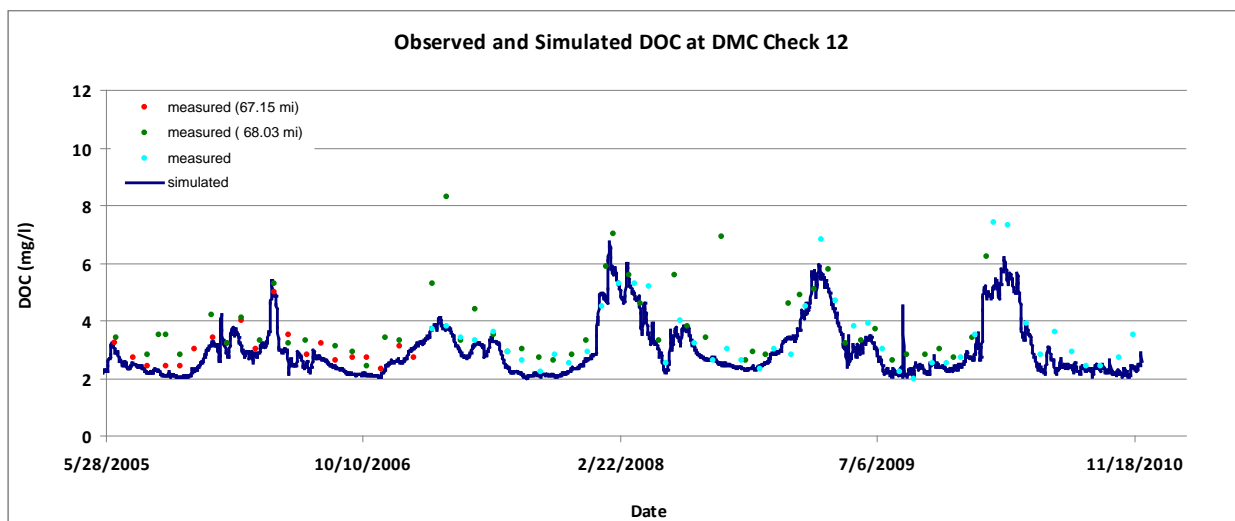
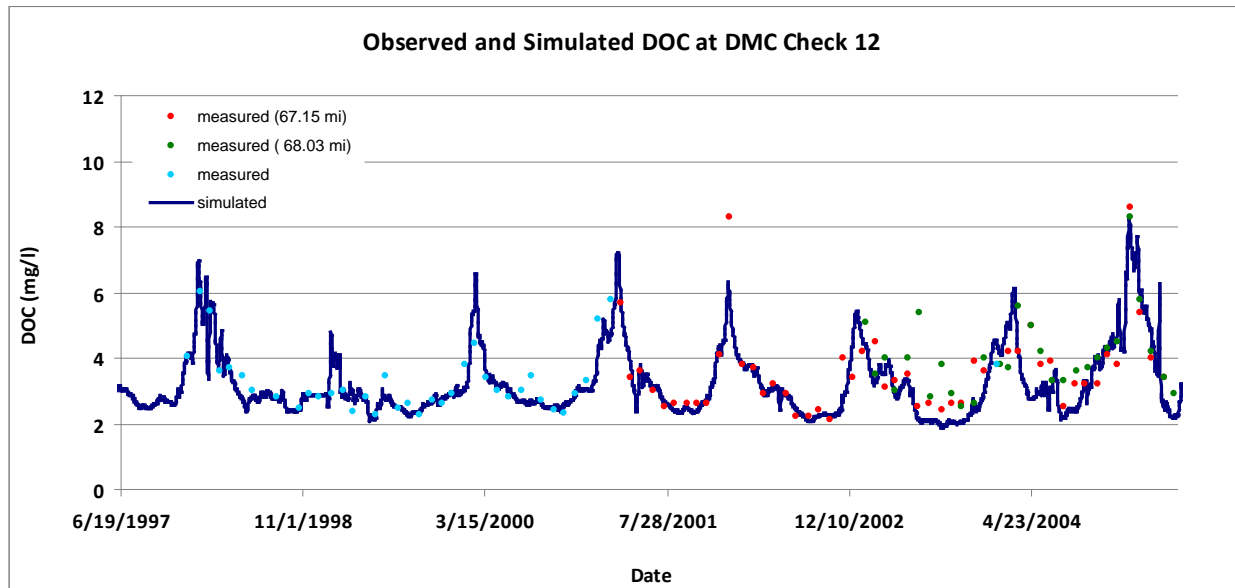


Figure 4.110 Comparison of Measured and Simulated DOC at Del Valle Check 7, South Bay Aqueduct

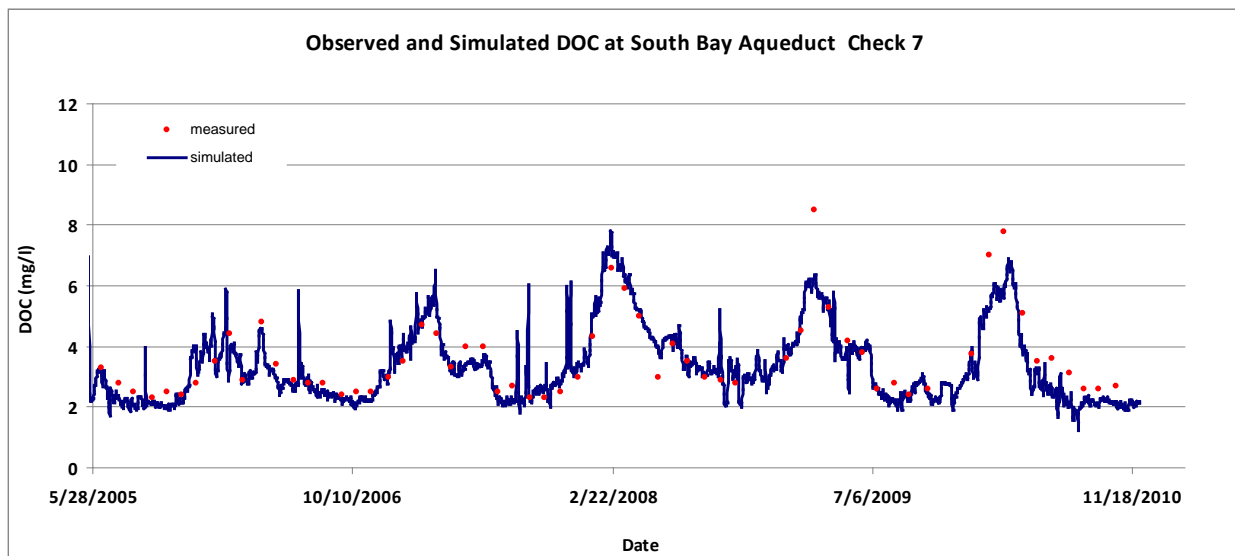
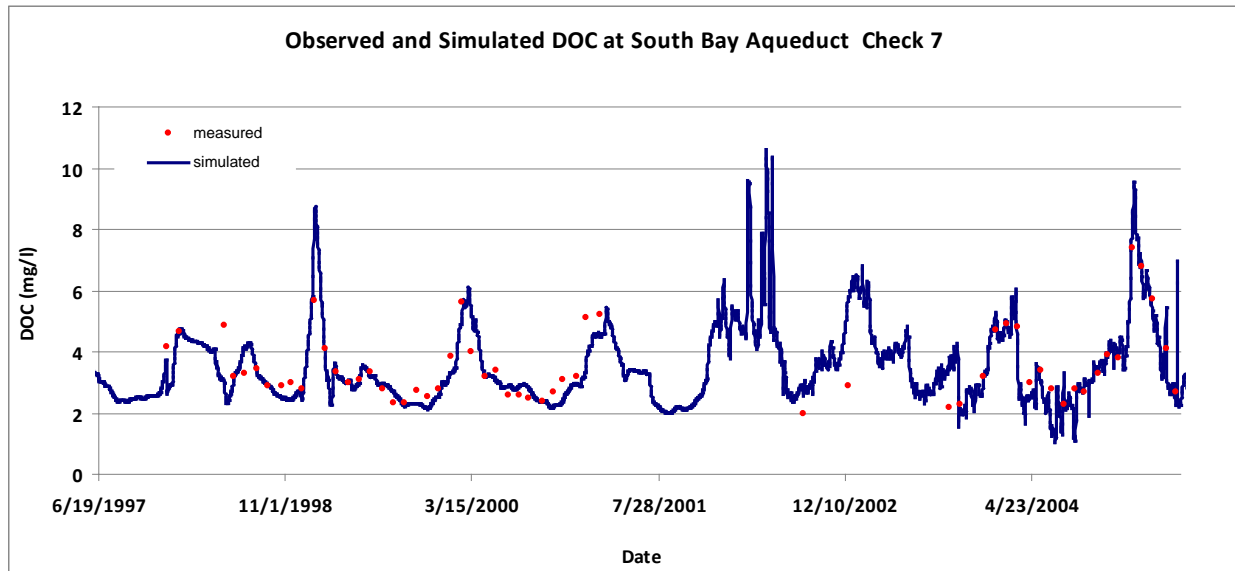


Figure 4.111 Scatter Plot for DOC at California Aqueduct Check 12

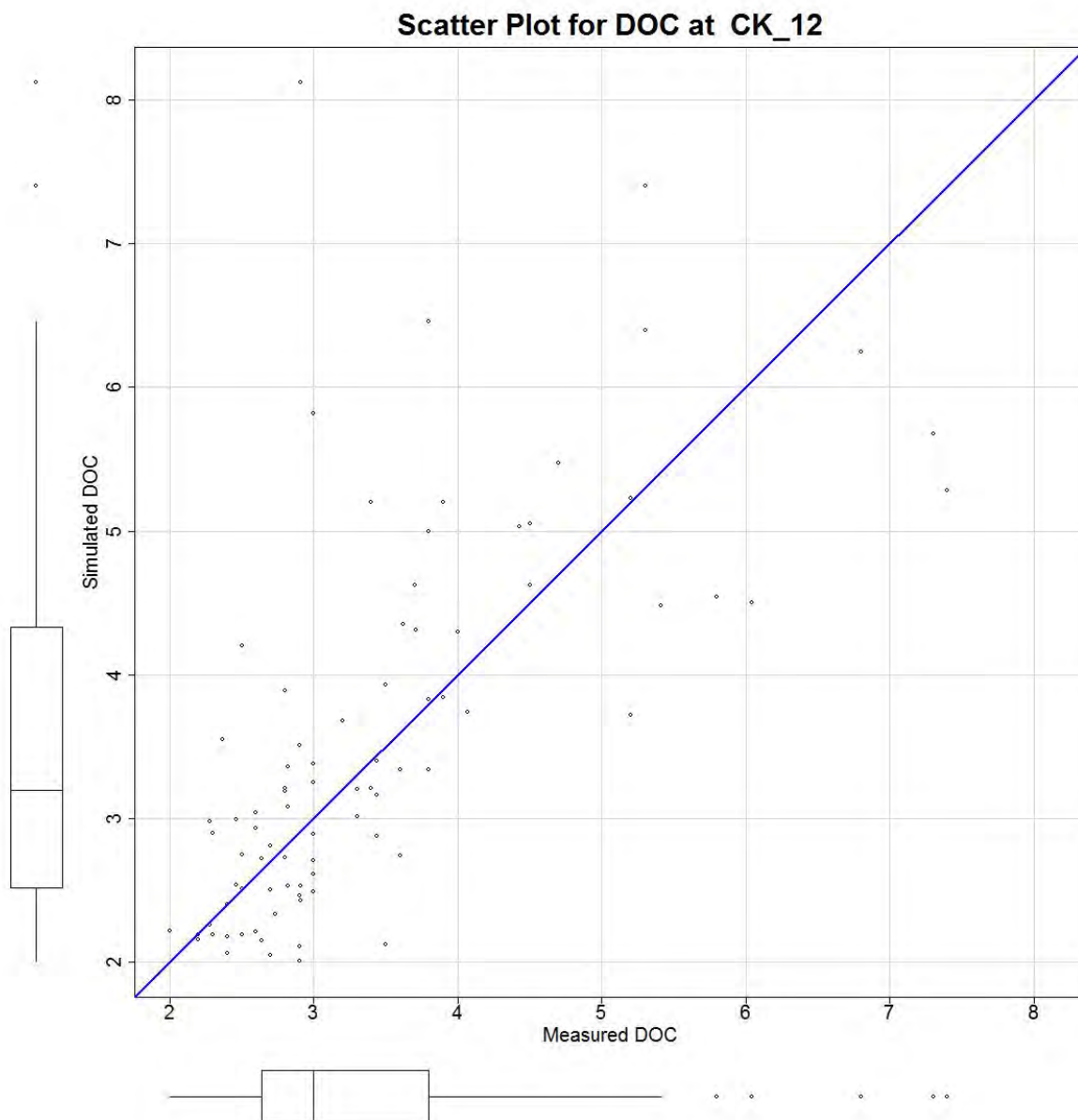


Figure 4.112 Scatter Plot for DOC at California Aqueduct Check 13

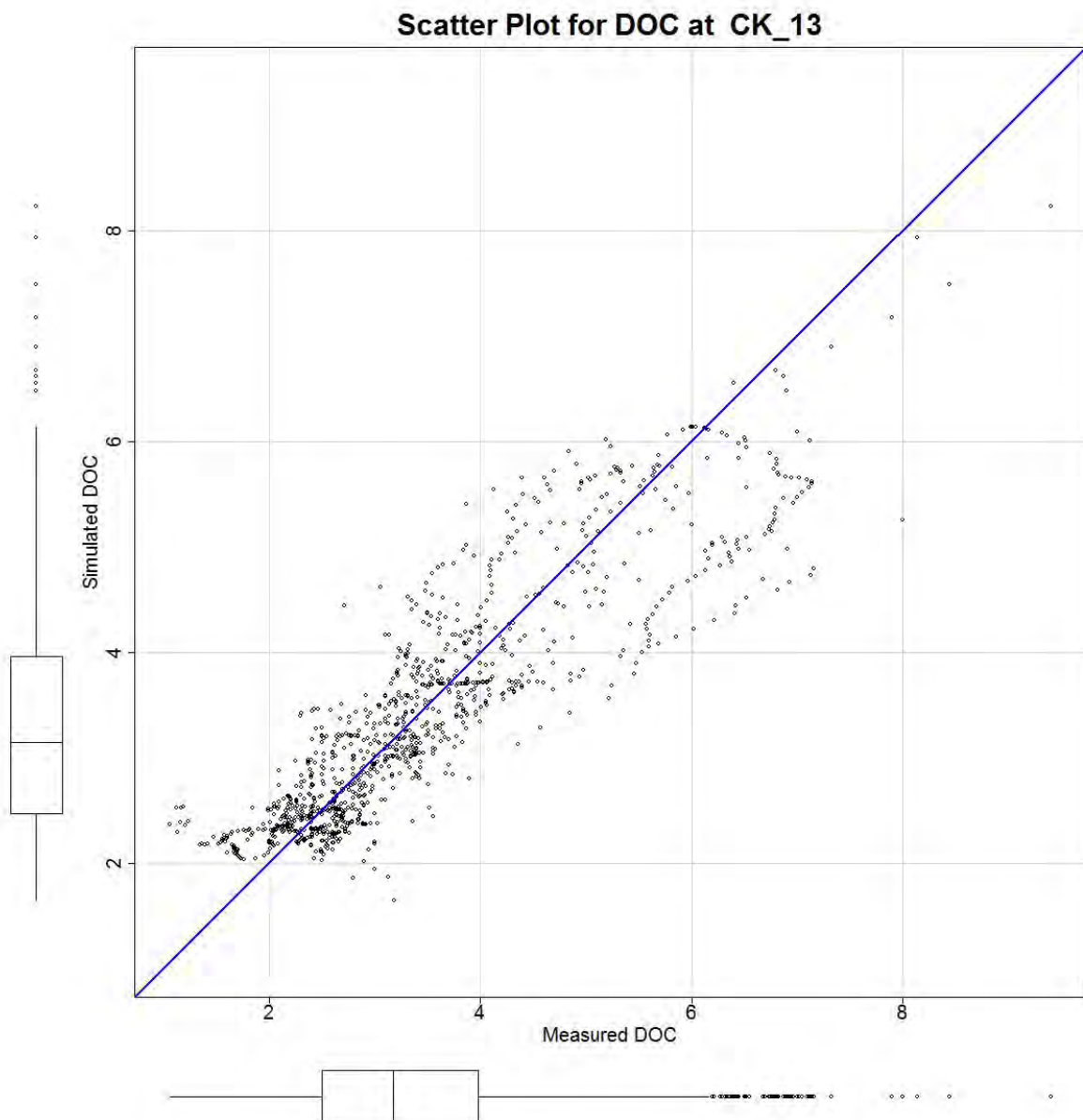


Figure 4.113 Scatter Plot for DOC at California Aqueduct Check 21

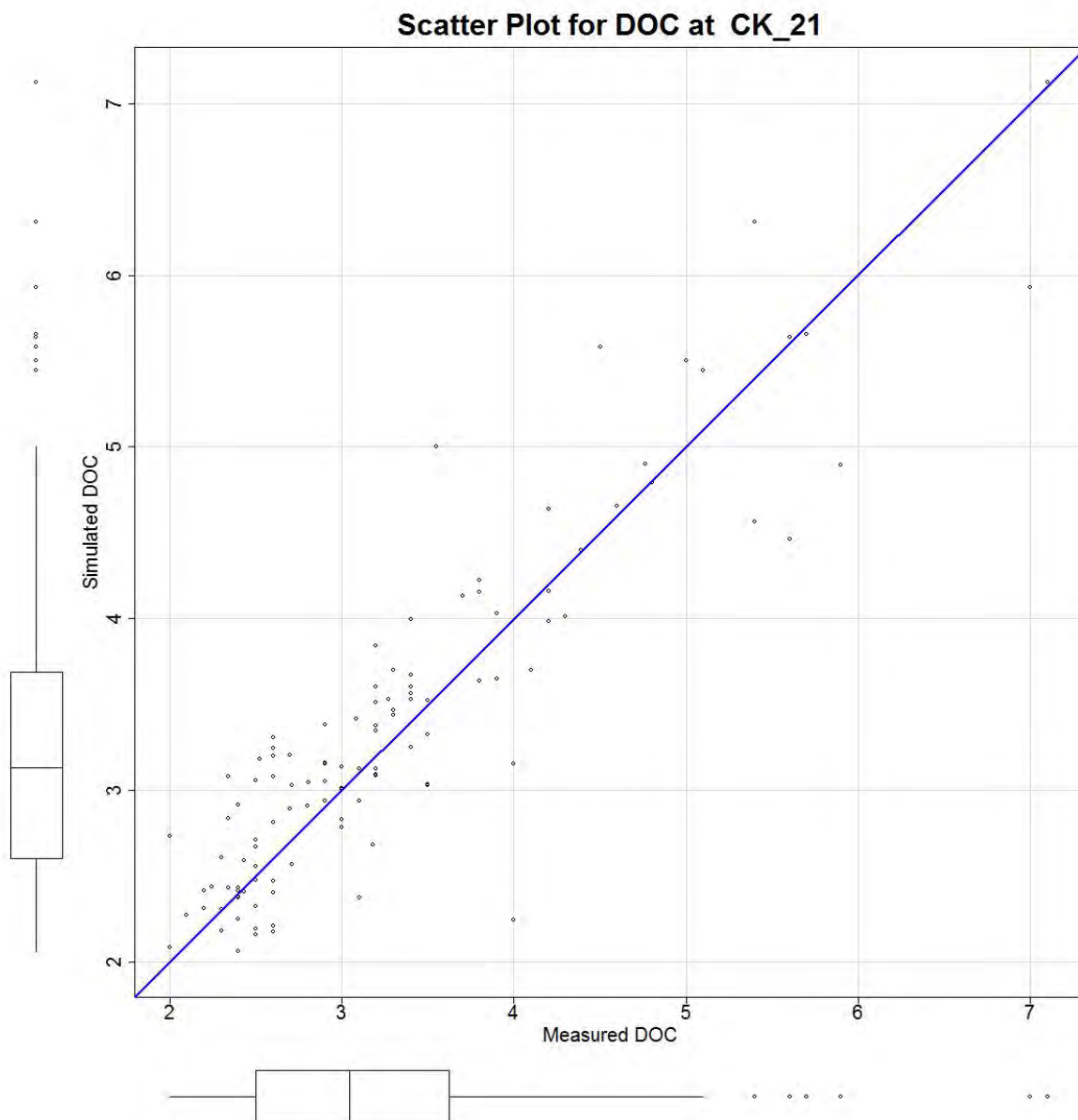


Figure 4.114 Scatter Plot for DOC at California Aqueduct Check 29

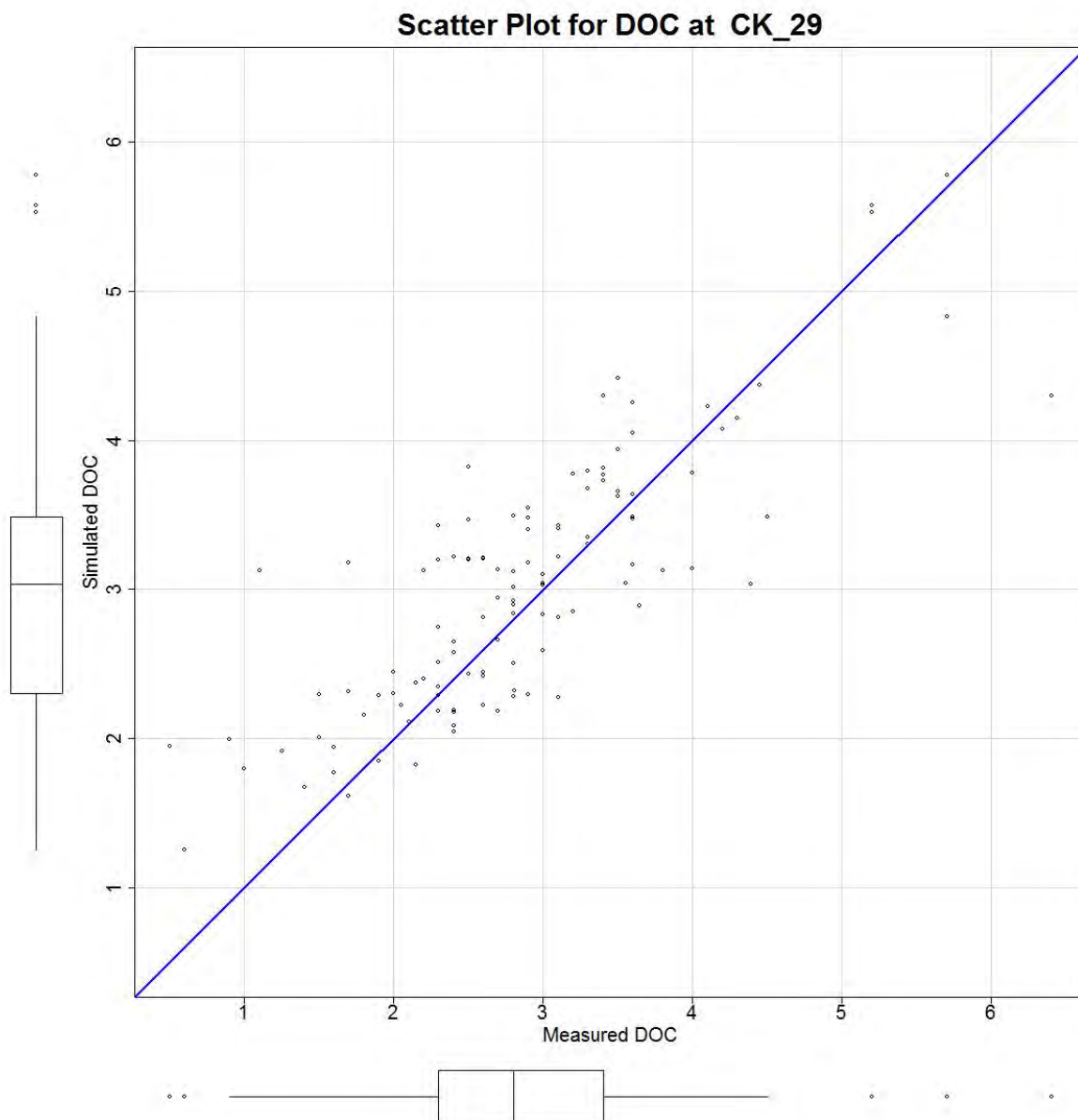


Figure 4.115 Scatter Plot for DOC at California Aqueduct Check 41

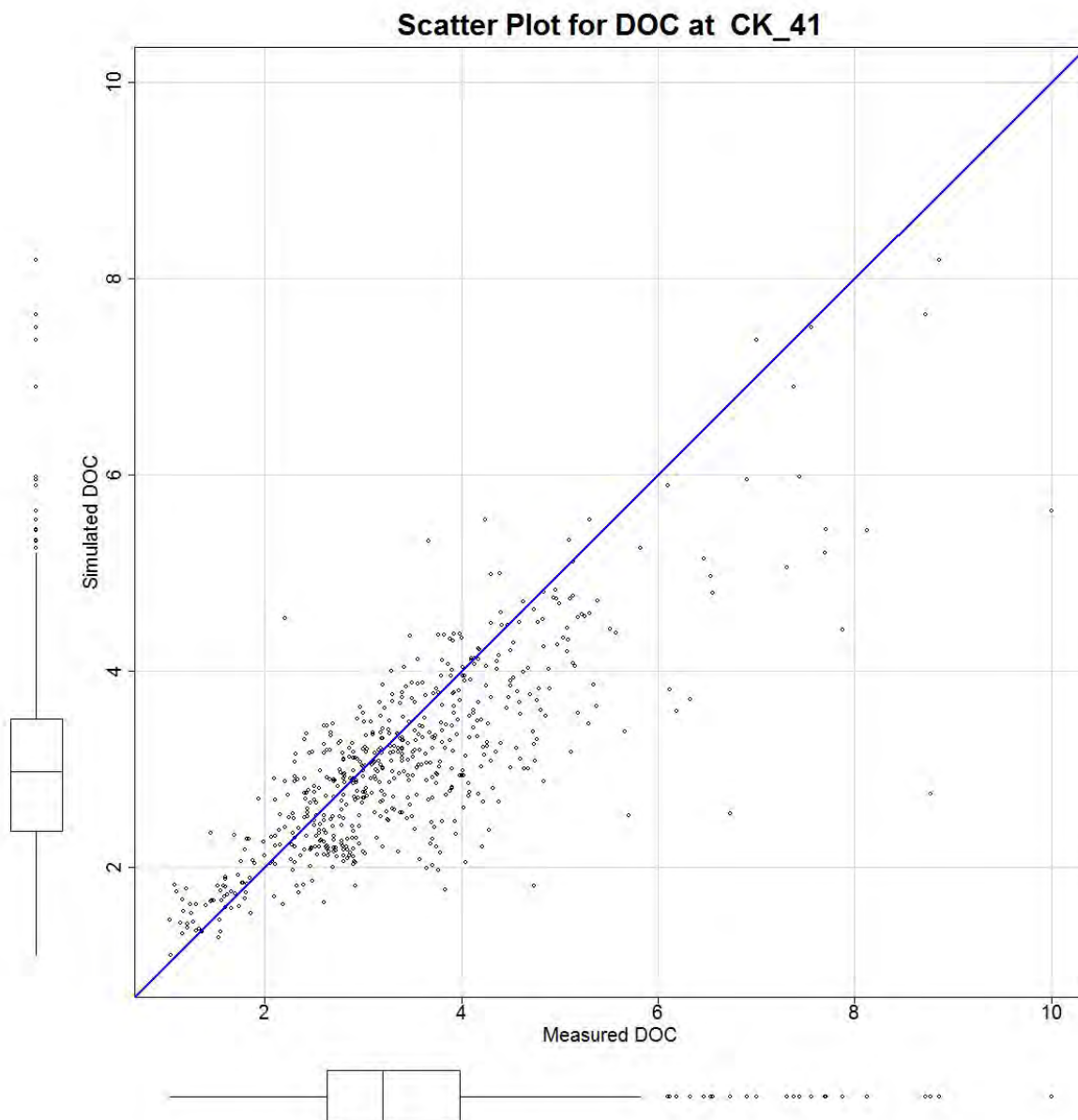


Figure 4.116 Scatter Plot for DOC at California Aqueduct Check

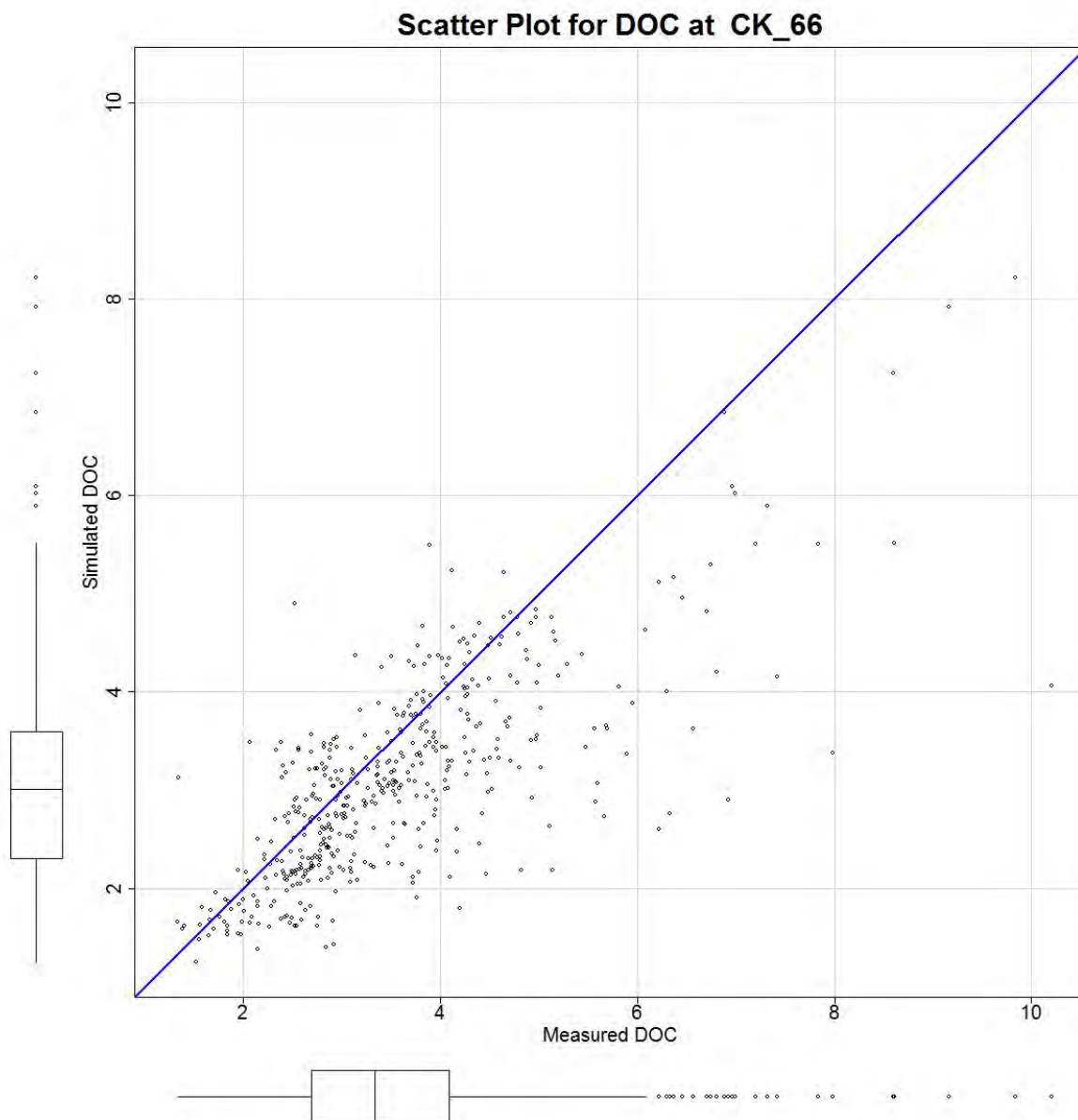


Figure 4.117 Scatter Plot for DOC at Del Valle Check 7, South Bay Aqueduct

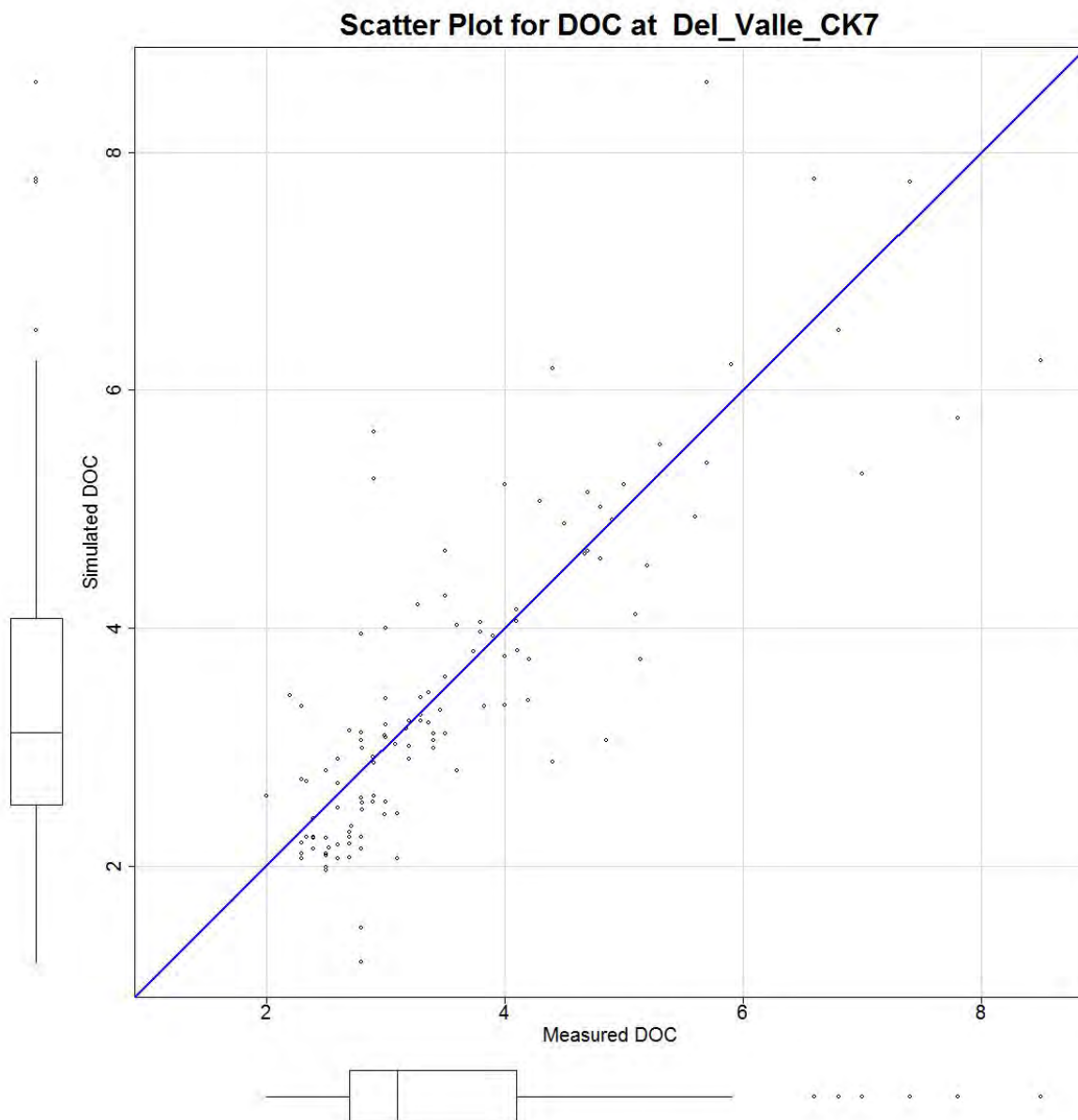


Figure 4.118 Scatter Plot for DOC at DMC Check 12

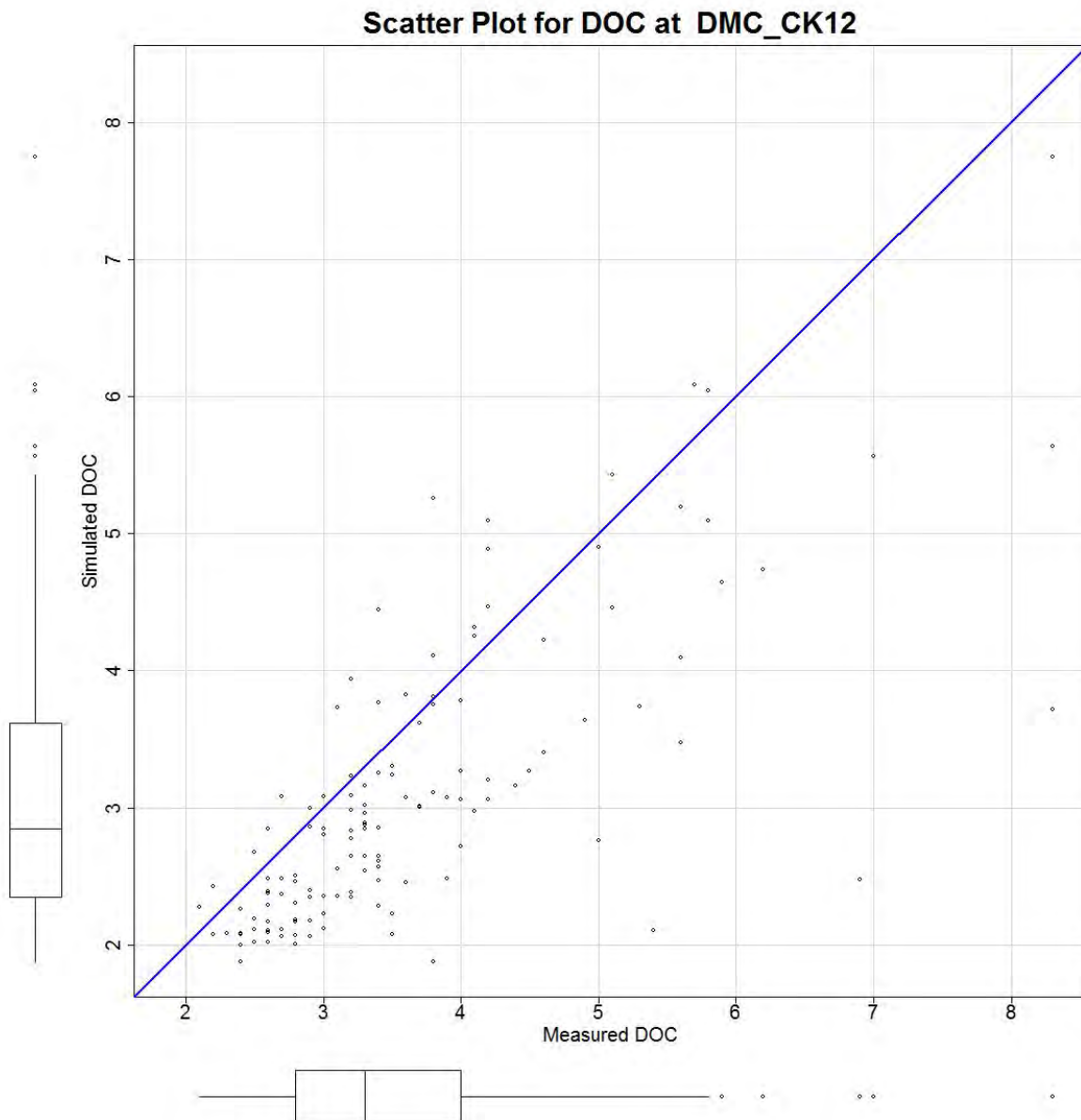


Figure 4.119 Scatter Plot for DOC at San Luis Reservoir

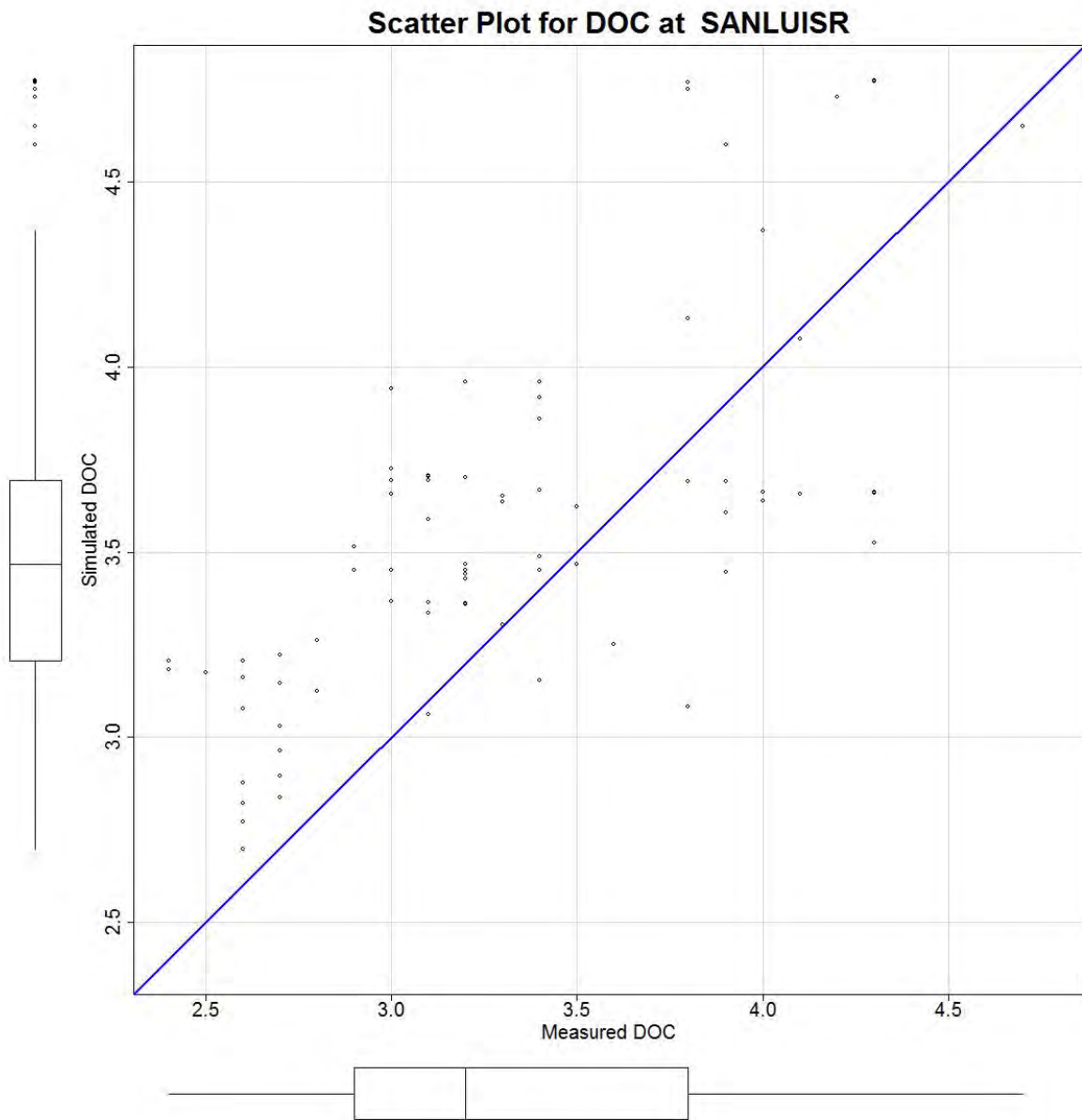


Figure 4.120 Exceedance Curve for DOC at California Aqueduct Check 12

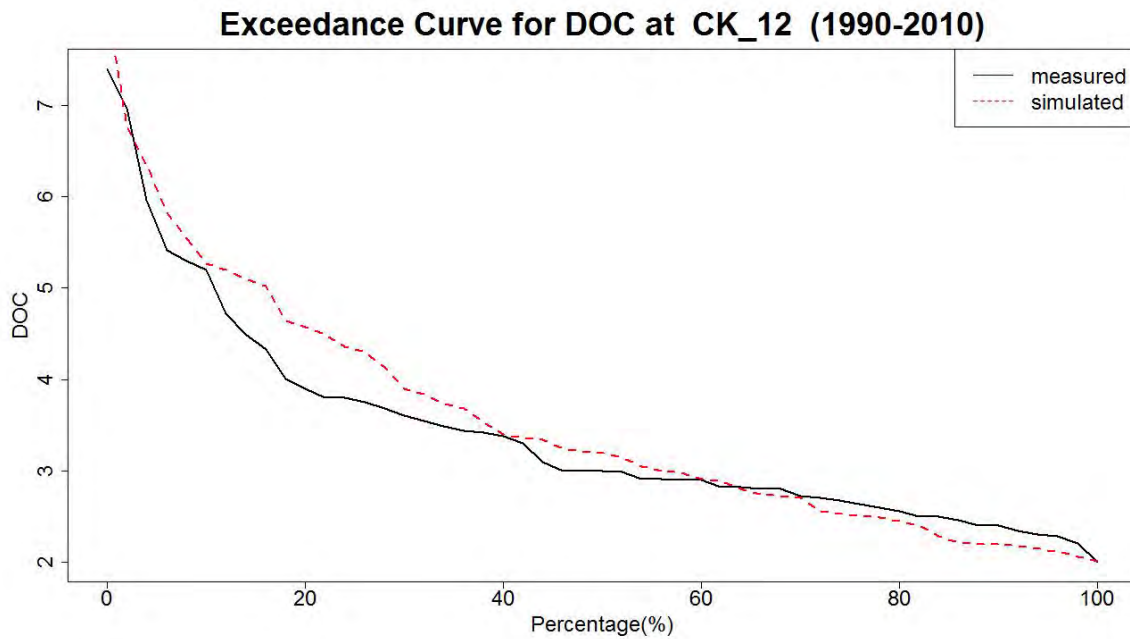


Figure 4.121 Exceedance Curve for DOC at California Aqueduct Check 13

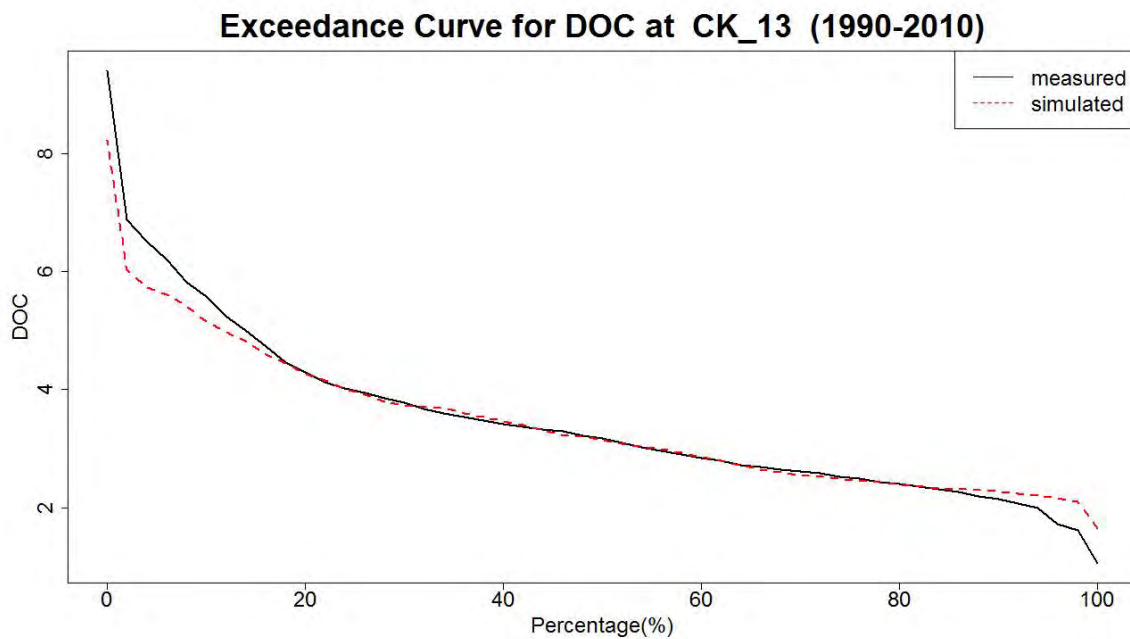


Figure 4.122 Exceedance Curve for DOC at California Aqueduct Check 21

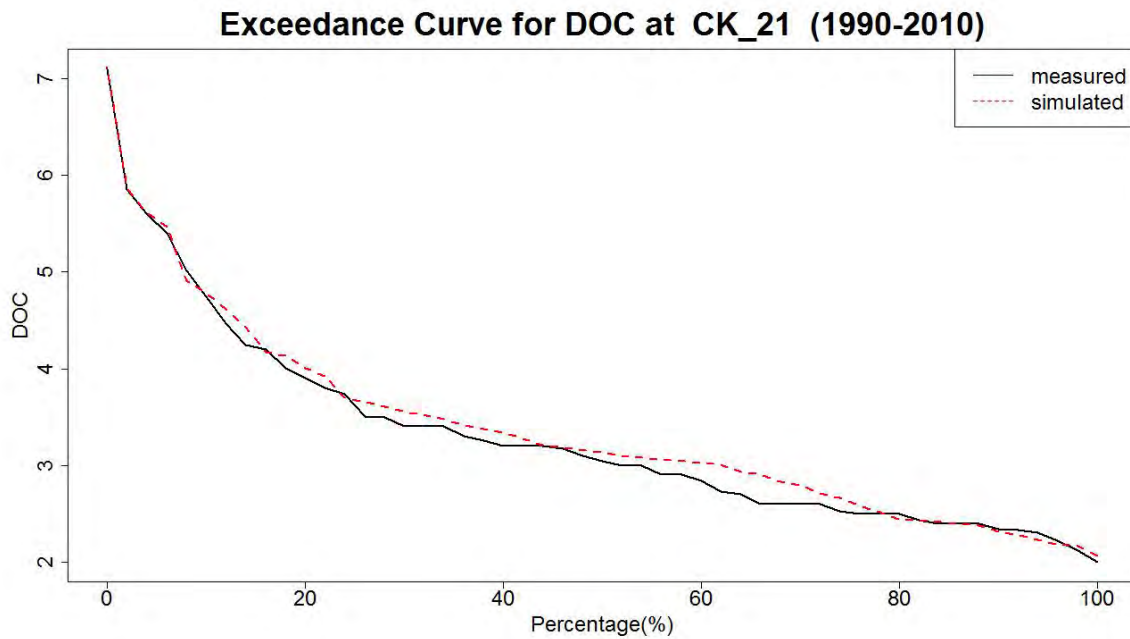


Figure 4.123 Exceedance Curve for DOC at California Aqueduct Check 29

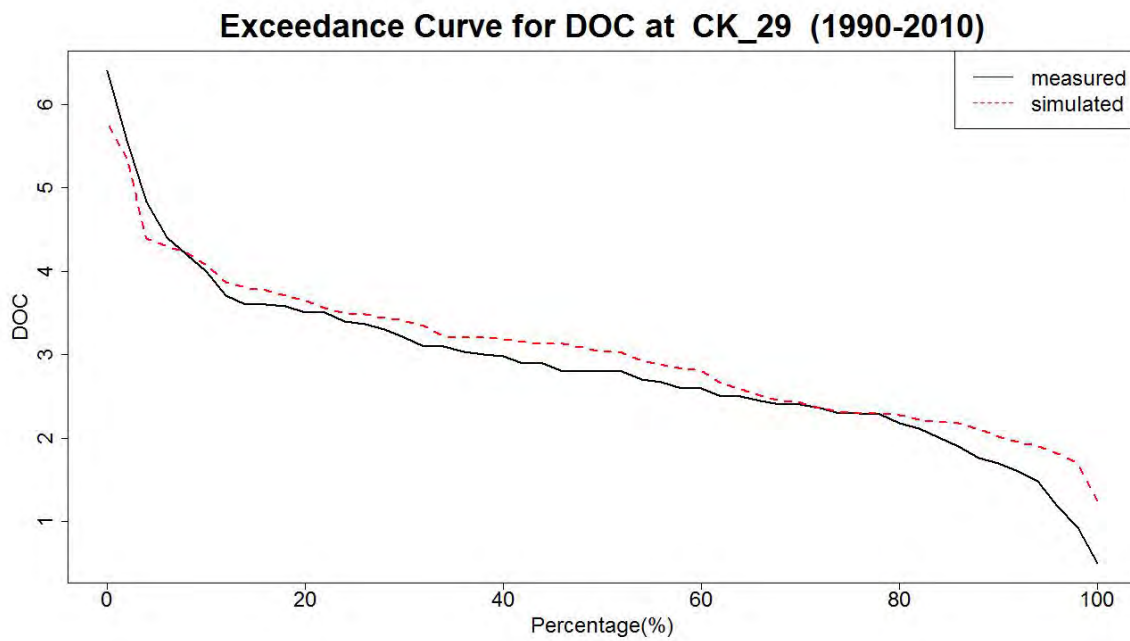


Figure 4.124 Exceedance Curve for DOC at California Aqueduct Check 41

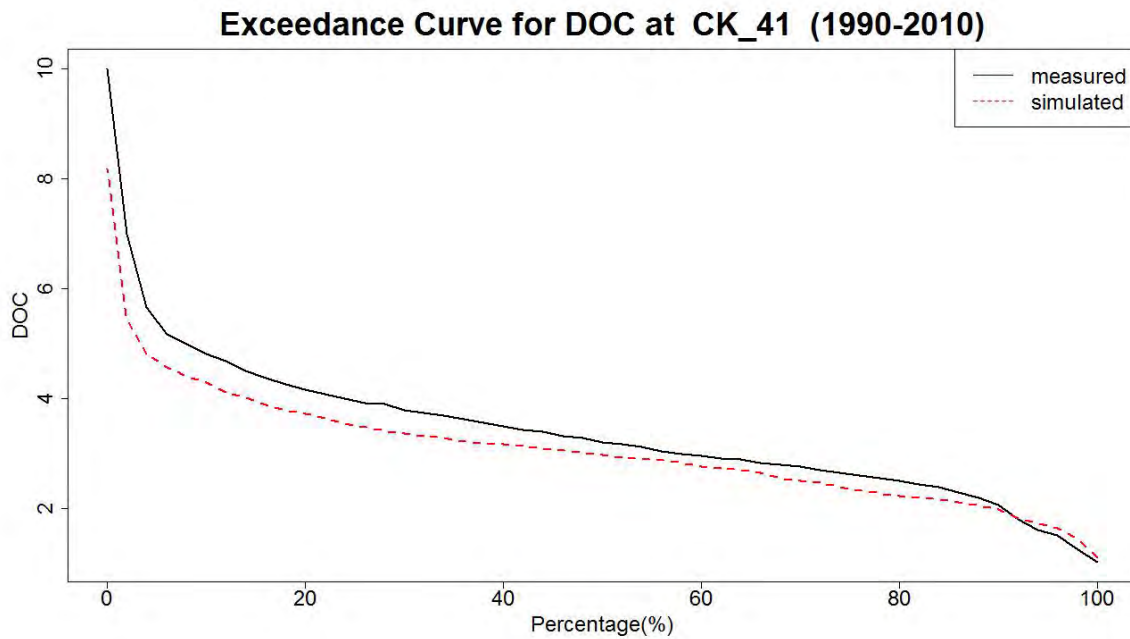


Figure 4.125 Exceedance Curve for DOC at California Aqueduct Check 66

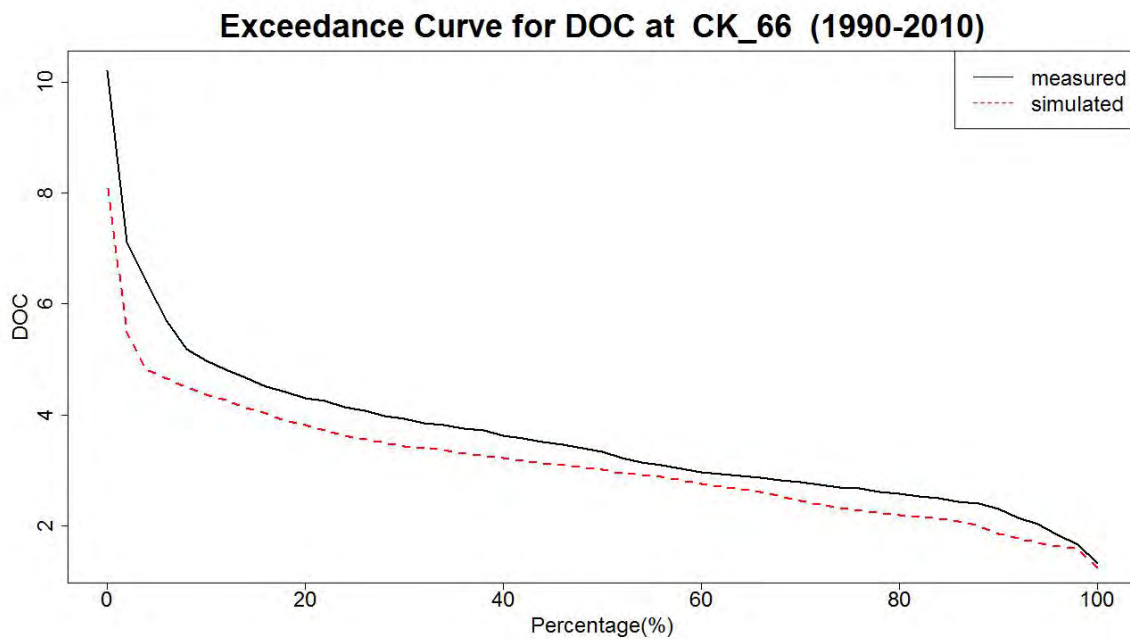


Figure 4.126 Exceedance Curve for DOC at Del Valle Check 7, South Bay Aqueduct

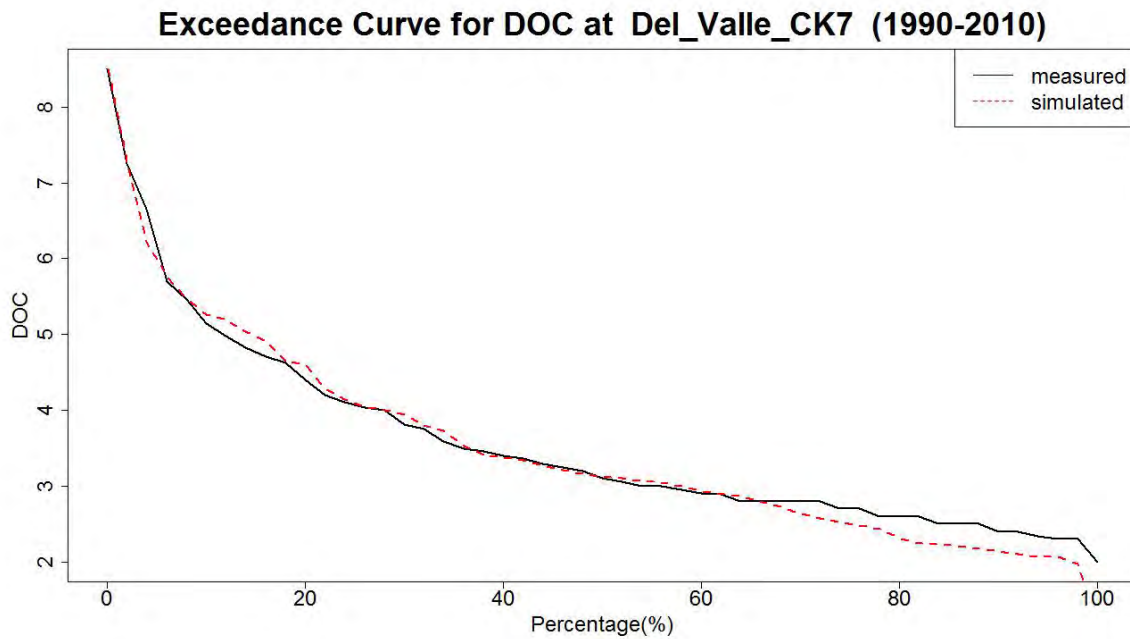


Figure 4.127 Exceedance Curve for DOC at DMC Check 12

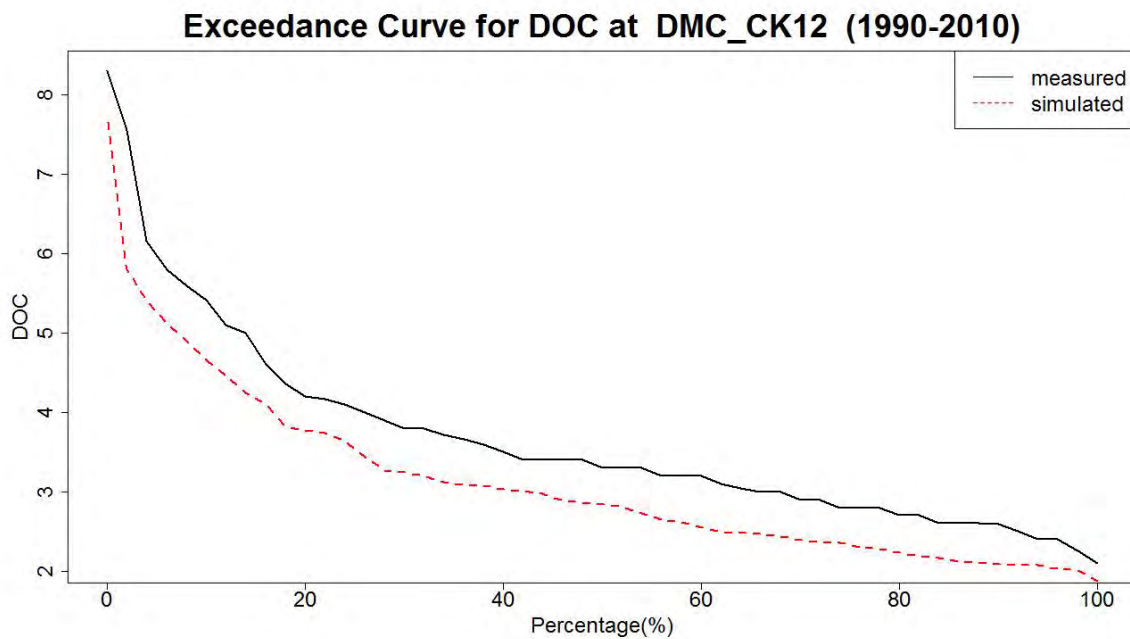


Figure 4.128 Exceedance Curve for DOC at San Luis Reservoir

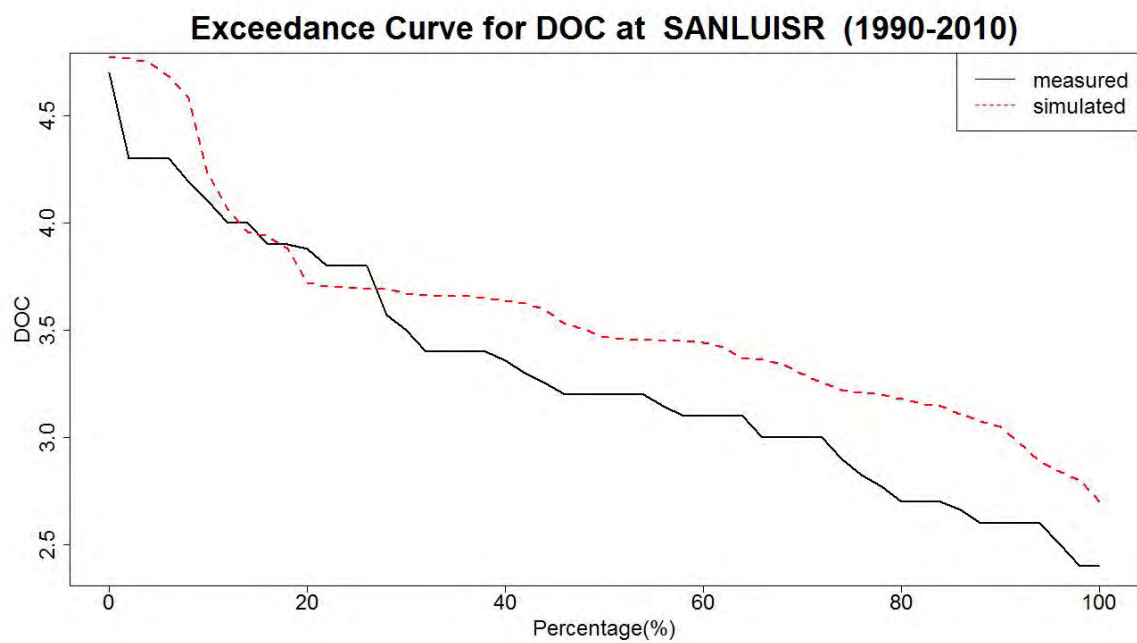


Figure 4.129 Month by Month Comparison of Measured and Simulated DOC at California Aqueduct Check 12

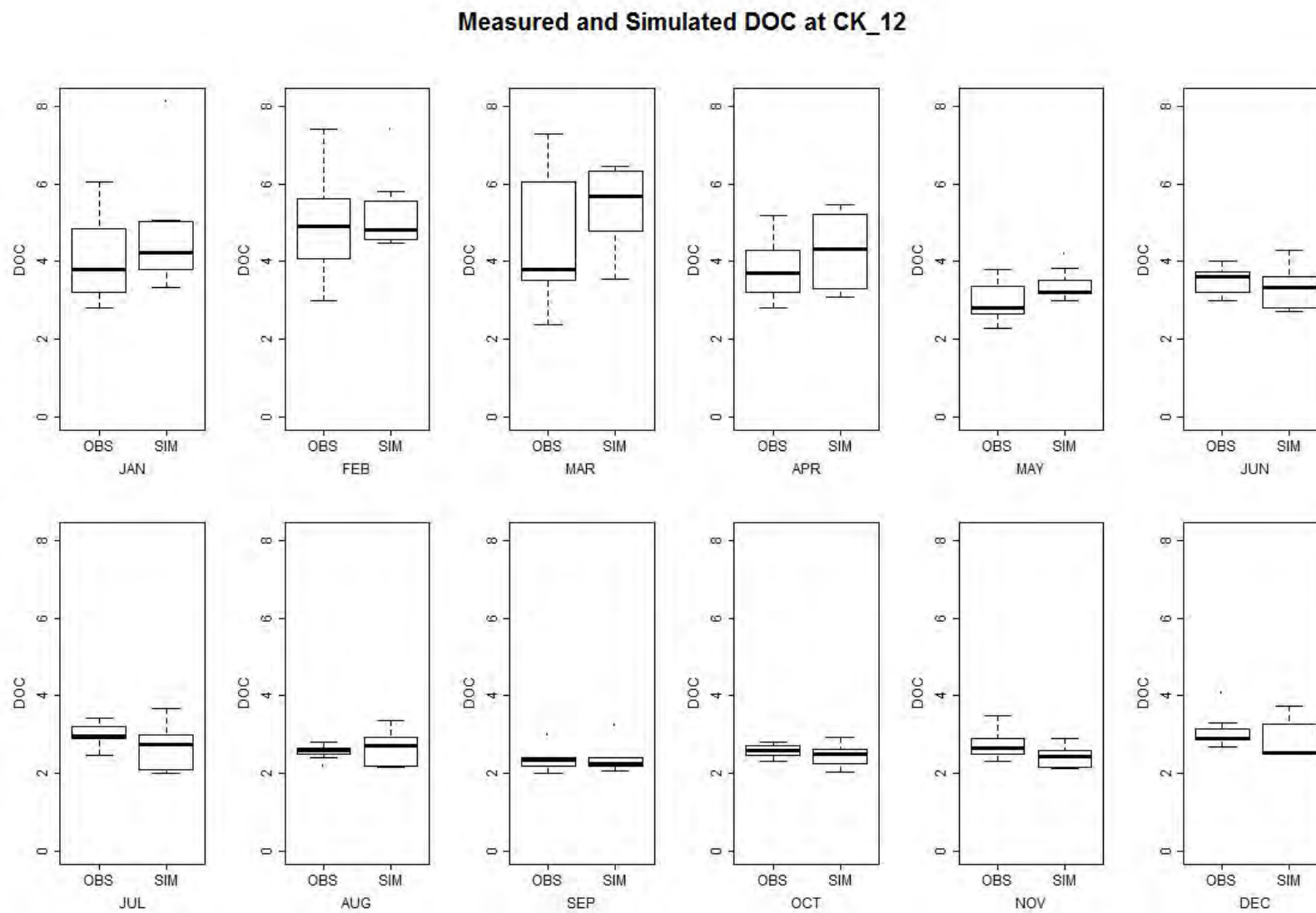


Figure 4.130 Month by Month Comparison of Measured and Simulated DOC at California Aqueduct Check 13

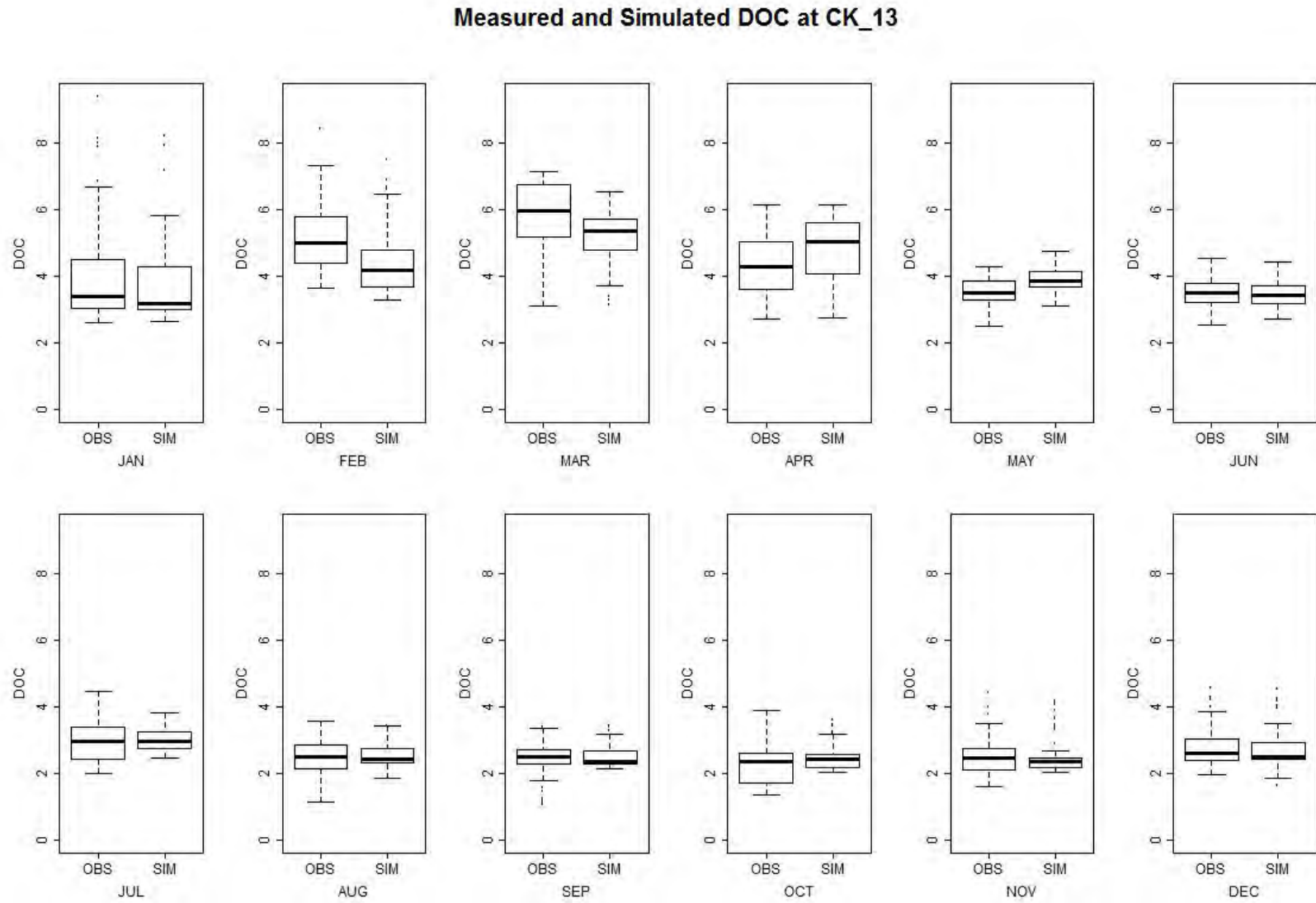


Figure 4.131 Month by Month Comparison of Measured and Simulated DOC at California Aqueduct Check 21

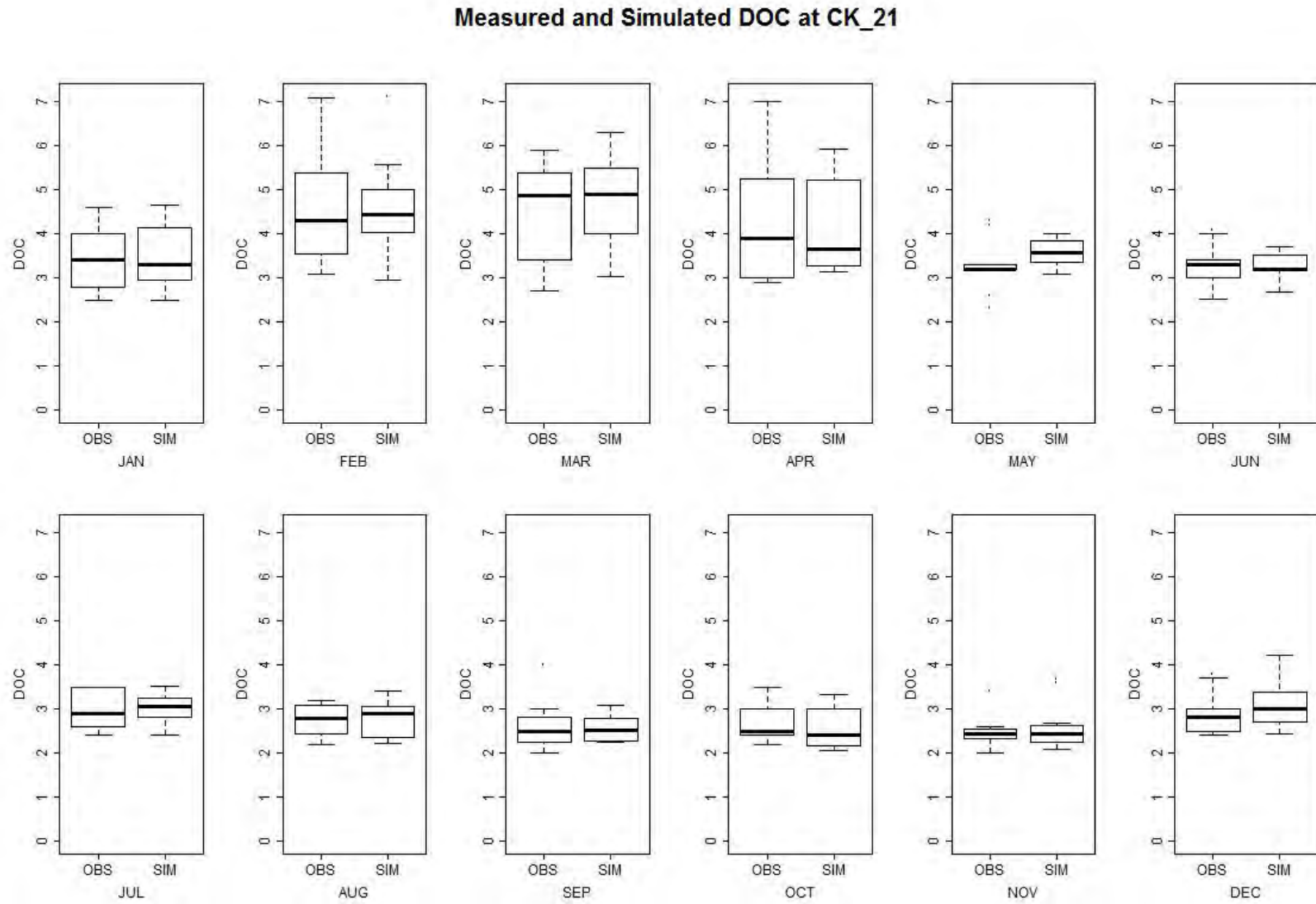


Figure 4.132 Month by Month Comparison of Measured and Simulated DOC at California Aqueduct Check 29

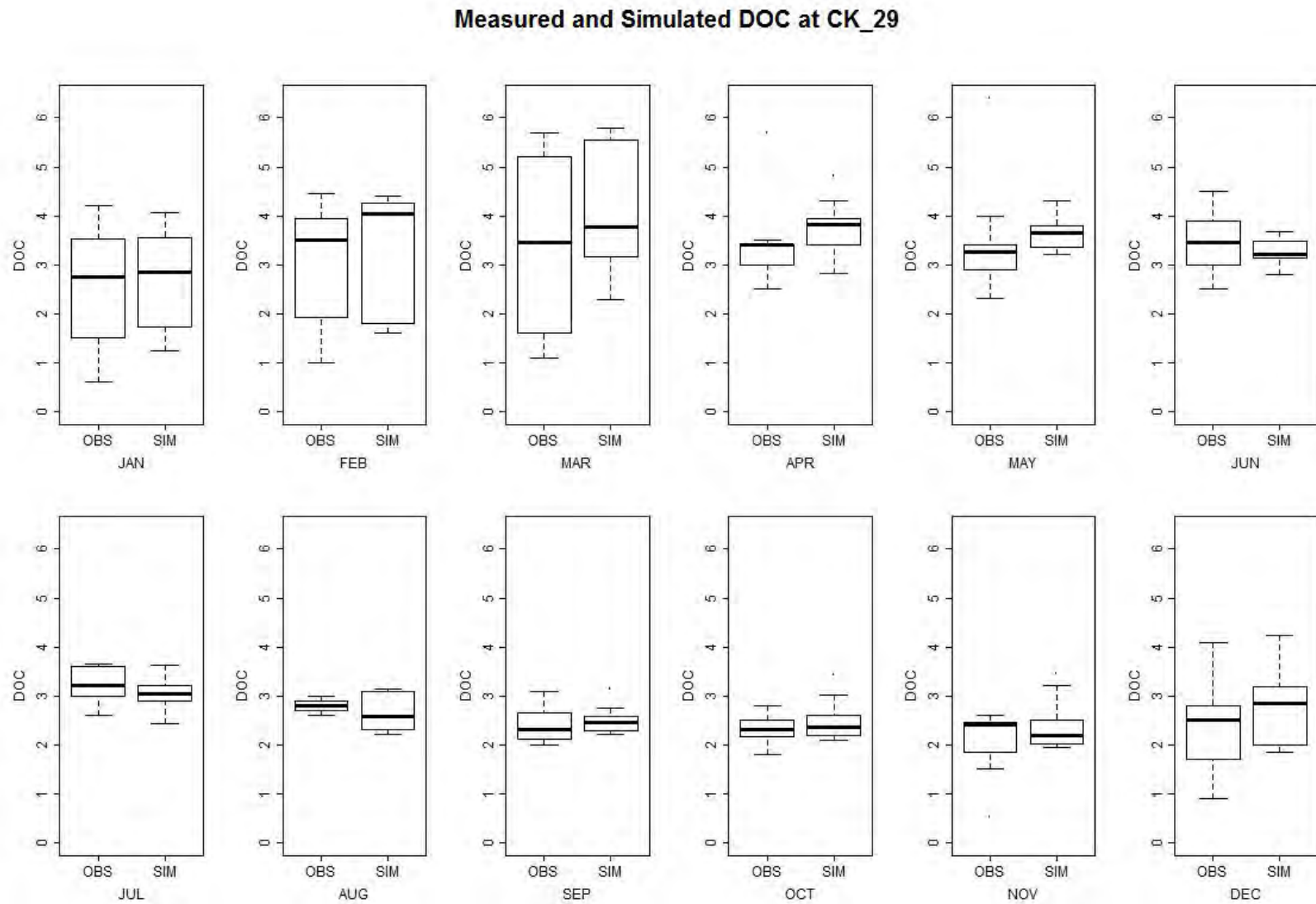


Figure 4.133 Month by Month Comparison of Measured and Simulated DOC at California Aqueduct Check 41

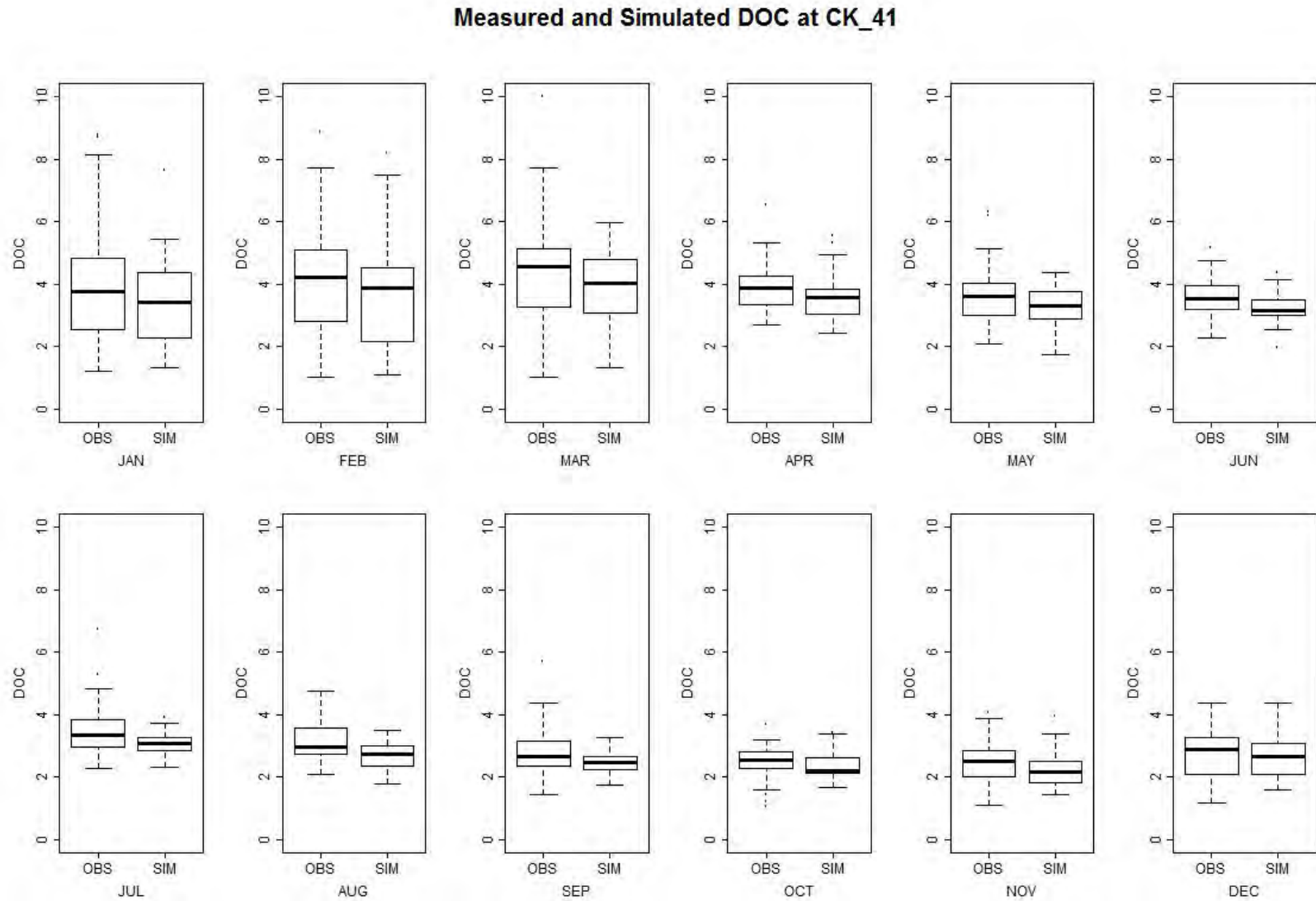


Figure 4.134 Month by Month Comparison of Measured and Simulated DOC at California Aqueduct Check 66

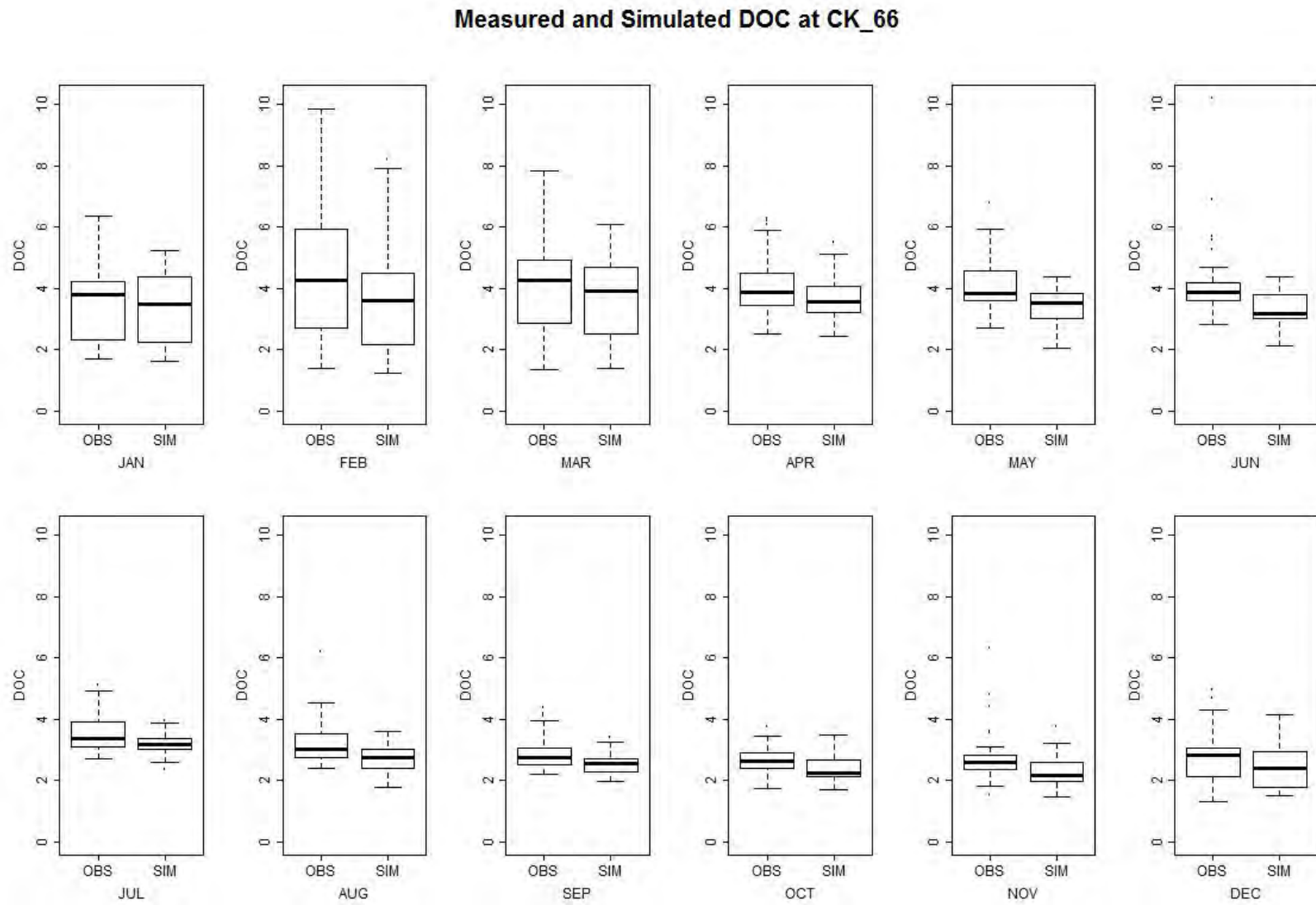


Figure 4.135 Month by Month Comparison of Measured and Simulated DOC at Del Valle Check 7, South Bay Aqueduct

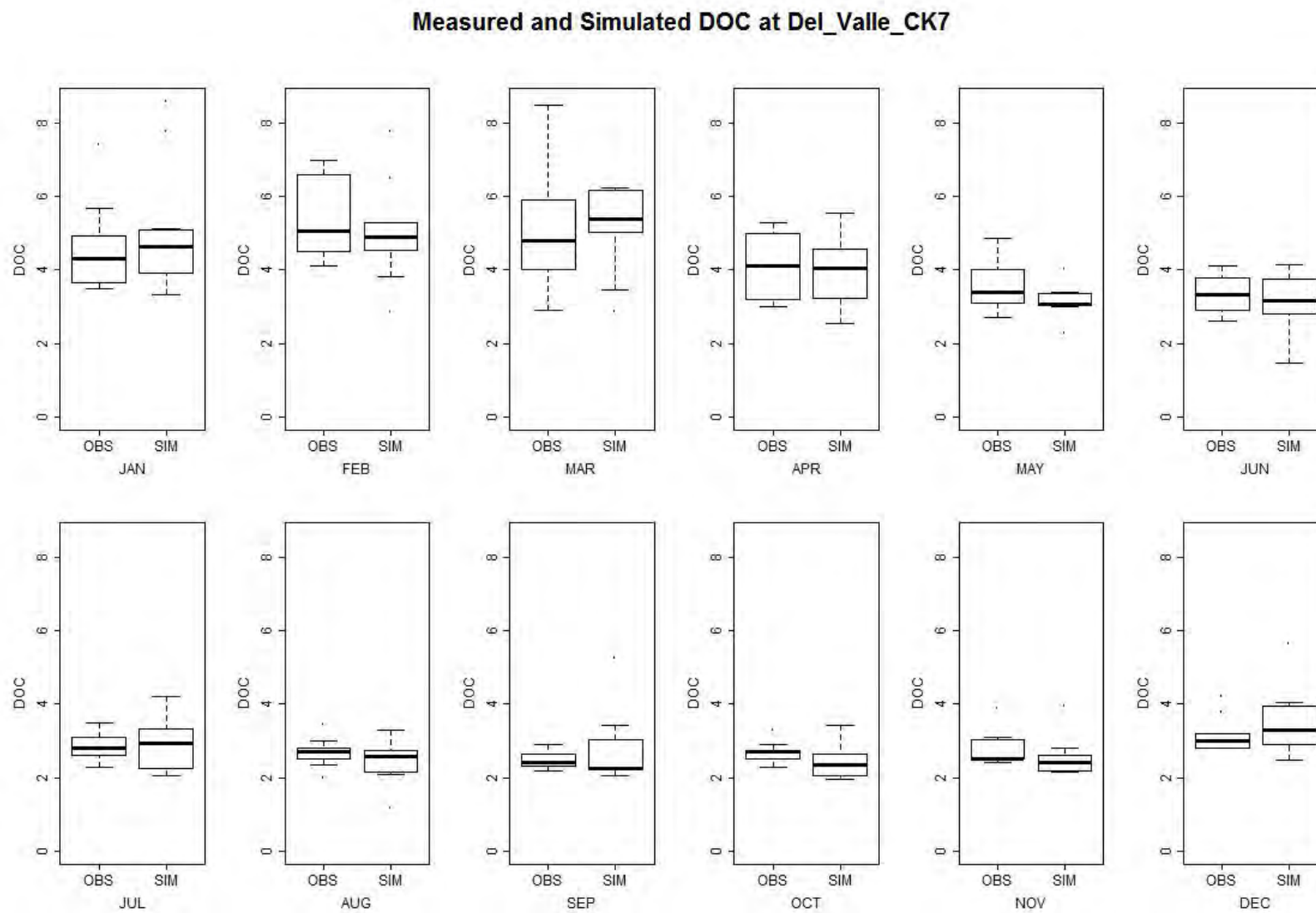


Figure 4.136 Month by Month Comparison of Measured and Simulated DOC at DMC Check 12

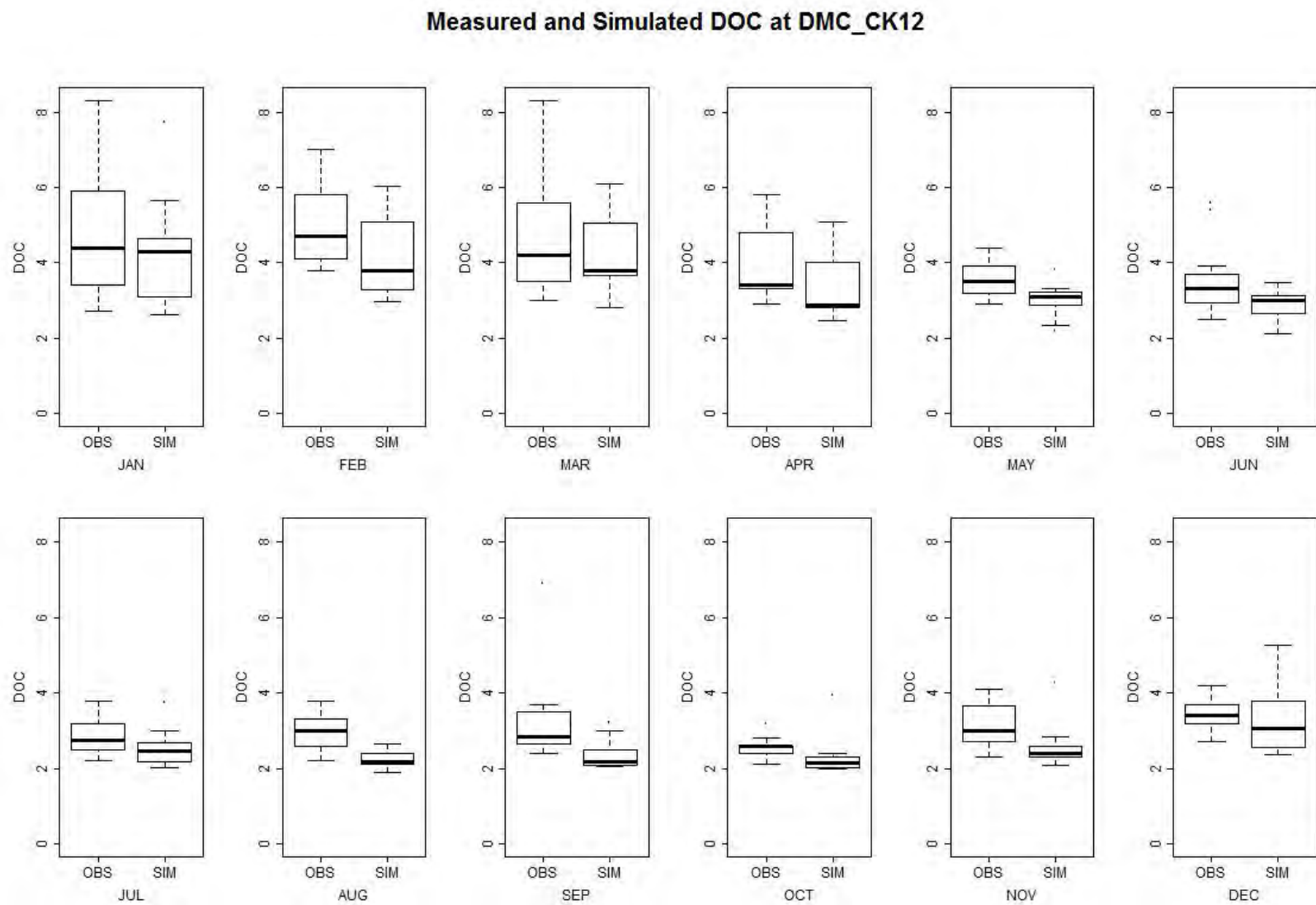
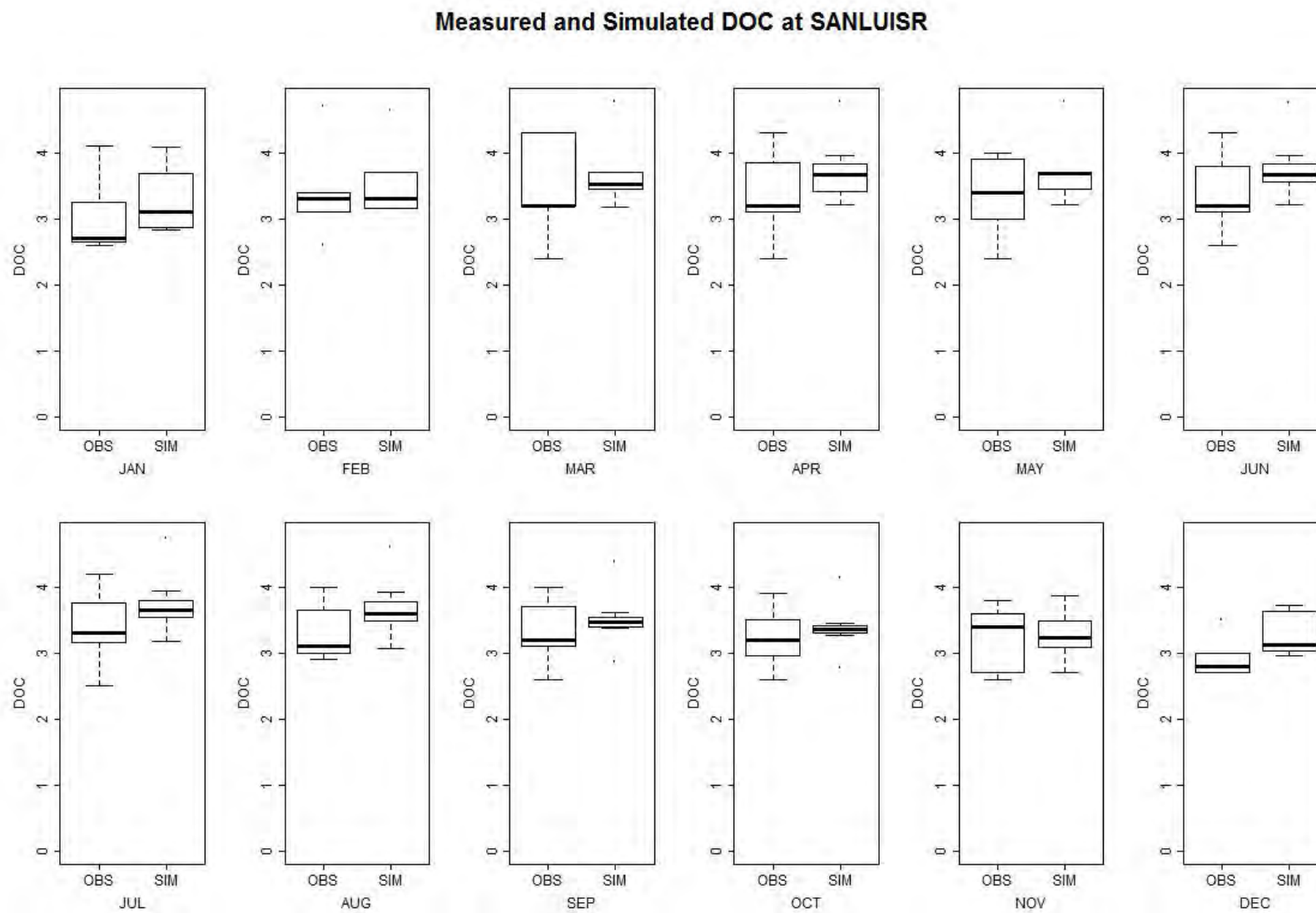


Figure 4.137 Month by Month Comparison of Measured and Simulated DOC at San Luis Reservoir



## 5. Model limitations

Like any other models, the Aqueduct model has its limitations. The model was based on a 1-D DSM2 program. It cannot be used to accurately answer questions that involve more than one dimension. Since DSM2 is a 1-D model, reservoirs are treated as completely mixed, vertical-walled bodies of water. So for a water body, no matter how big the capacity is, there is only one value at a time for a variable.

Unlike the Delta DSM2 model, which has unlimited water source from tidal boundary, the water available to the Aqueduct and DMC system is restricted by pumping at Banks and Jones Pumping Plant. Model removed from the system must not exceed water added to the system, so a strict mass balance must be maintained in order for the model to run successfully. This requires that hydrologic inputs, i.e. inflows, outflows, rainfall, evaporation, storage and etc must be consistent. Otherwise, gains / losses be considered to avoid problems such as channel drying (not enough water), or overbank flow (too much water). The use of gains / losses has an impact on water quality modeling.

In general, the check structures try to maintain a near constant pool elevation in any given pool. This is the main reason that in the model, the check structures are modeled as broad-crested weirs, with the invert elevations fixed to control flow. The DSM2 (version 8) allows users to define rules for gate operations. This usually involves specifying flow rates, or stages as conditions for gate operations. BDO staff has spent limited time on trying to use operation rules for gate operations, but without luck. The model would not converge for most of the time steps, thus the results cannot be trusted. The reason for this is not clear. Further investigation is needed to find the problem.

There are limitations with diversion flows and some source flows. The data quantifying diversions from the system are aggregated on a monthly basis. These data were used to specify the diversions in the model, and were assumed to remain constant over the month. It is unrealistic to specify daily water quality input for groundwater pump-in and storm water flow. Instead, a constant water quality input is specified for each source flow. In reality, diversions, water quality of groundwater and stormwater may have dramatic change from day to day. It is impossible for the model to catch the changes because of the limitation of sparse inputs. .

## 6. Conclusions

The DSM2 extension model, which was calibrated by CH2MHILL in 2005 to calculate flows and salinity, was verified using 21-year historical hydrologic and water quality data. The model was extended to simulate Bromide and DOC besides EC.

The model can simulate water quality (EC) reasonably well. As expected, the results are less accurate when locations are farther away from boundaries, i.e. Jones and Banks PP. For San Luis Reservoir, simulated EC matched observed EC reasonably well. For the period from 1990 to 2002, and 2010, the model did a good job in estimating EC. For the period from 2003 to 2009, however, the model underestimated EC at San Luis Reservoir by a small amount.

Measured data on Bromide is sparse. Based on limited measured data, the simulated Bromide output matched measured Bromide data well for SWP Checks 13, 21, 29, 339, 41, and 66, DMC Check 12, South Bay Aqueduct Check 7 and San Luis Reservoir. Measured Bromide data shows that Bromide concentration at San Luis Reservoir varied between 0.2 and 0.3 mg/l almost all the time.

The model did not do as well in modeling DOC as it did in modeling EC and Bromide when comparison was based solely on N-S Coefficients. The model underestimated DOC at Checks 41, 66 and DMC Check 12. For San Luis reservoir, the model underestimated DOC for the period between 2004 and 2007; the model simulated DOC reasonably well for the period between 2008 and 2010. DOC decay may play a role in the mismatch between modeled and measured DOC. Another factor may be that DOC was sampled at Pacheco pumping plant rather than at a location near Gianelli Pumping / Generating Plant. Even for locations with low N-S coefficients, the model did a decent job by following trend well. DOC decay from upstream checks to downstream checks is not obvious. No seasonal trend of DOC decay is observed. Models results show that it is reasonable to model DOC as a conservative constituent.

Treating San Luis Reservoir as completely mixed body of water is sufficient for meaningful results. As expected, the magnitude of changes in EC, DOC, and Bromide at San Luis Reservoir is quite small than that of EC, DOC, and Bromide changes at SWP Checks. The model was able to catch the smaller changes.

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